A GLACIER (THE MER DE GLACE, WITH THE GRANDES JORASSES IN THE DISTANCE).

THE

STORY OF OUR PLANET

BY

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PREFACE.

In writing this volume I have not had any intention of attempting to add another to the text-books of geology in the English language. Of these there is already an ample supply. Sir A. Geikie's "Text-book of Geology," Professor Prestwich's "Geology," and the edition of Phillips' "Manual of Geology" by Professor H. G. Seeley and Mr. R. Etheridge leave no gap to be filled among works of larger size, while a student not yet ripe for these has ample choice among books on smaller scale, which can be arranged in a graduated series from Mr. Jukes-Browne's "Handbook" to the most elementary "Primer."

So I have not endeavored to write a book which is designed to prepare for an examination or to serve as a guide to the literature of the subject. A class of persons, however, still exists to whom I hope this volume may be acceptable and useful. Many who, to use the common phrase, have received a good education, though they feel much interest in the history of the earth on which they live, have neither the leisure nor the inclination to master the technicalities or to enter into the minute details of any one branch of science. At the present time there is, I think, a real danger lest such persons should be repelled from all knowledge of science by its increasing complexity. To speak of geology only: Forty years since a book dealing with the main principles of geology, such as Sir C. Lyell's well-known work, would have been understood with little difficulty by any man of good general education: two pages of print would have contained all the technical terms which had to be mastered. But these have now become so numerous that the beginner has not only to comprehend new ideas, but also to learn a new language. To some extent this is inevitable. As science increases in scope and complexity technical terms become more necessary. They are helpful in expressing ideas concisely and precisely; still they tend inevitably to diminish the number of those who take an interest in any subject, and to restrict all study of it to those who make it a profession. This may prove ultimately prejudicial by fostering a narrowness in

its votaries, both of views and of sympathies. No doubt the judgment of experts is less fallible than *vox populi;* but experts sometimes suffer from an hypertrophy of learning and an atrophy of common sense to which men of wider outlook and more general culture can apply a wholesome correction. Technical terms also, as I venture to think, are sometimes coined without good cause. The use of them seems to be pleasing to some minds, for it indicates an initiation in mysteries and a superiority to the common herd. But from a terminology not generally intelligible worse evils than the gratification of personal vanity are apt to arise—namely, the worship of phrases and the substitution of words for ideas. Science, as it grows, suffers from its epidemics, and high-sounding words are often the bacteria which communicate disease to mental constitutions of the less vigorous type. To some persons a sonorous term seems to be so satisfactory that it passes current for an idea, and is a mask for any amount of hazy indefiniteness. We are often told that plain living and high thinking go together in the daily life; may it not be that plain speech and accurate thought are not so far apart in science? An English phrase may require, when printed, a few more letters than a misbegotten compound of Greek words (often barbarous to the ears of a scholar); but it possesses this advantage, that he who runs may read, and he who speaks cannot clothe himself with grandiloquence as with a cloak, and conceal mental poverty beneath verbal splendor.

So, though technical terms cannot be wholly avoided, and the scientific names of plants and animals, as a rule, must be employed for the sake of precision, I have striven, as far as possible, to abstain from them, and to write as addressing men and women of good general education who might desire to know something of the methods of reasoning which are adopted in geology, and of the general conclusions to which these have led. But in trying to tell "the story of our planet" in fairly plain words I have not shrunk from dealing with some of the more difficult questions which it involves. In short, the plan on which this book has been framed is generally similar to that adopted by Sir C. Lyell in his great work "The Principles of Geology." But as it is now twenty-one years since the last edition of "The Principles" was published, and the representatives of its author, doubtless through reverence for his memory, have not attempted to revise or alter a work which is rightly numbered among our classics, there is, I believe, room for a book which covers somewhat the same ground.

Still I have not adhered at all closely to the lines followed by Sir C. Lyell, because at the time when he wrote many things had to be fully demonstrated which now (thanks largely to him) may be taken almost for granted. In some instances, however, I have ventured to draw upon the materials collected by him, and have freely used throughout this book such facts as may be called the common property of all teachers of geology without deeming it necessary always to indicate the source from which they were derived. As a rule, I have only inserted references where the actual words of an author have been quoted; since, as already stated, this is not meant to be a text-book. It is founded on a part of my lecture notes, and, as everyone knows who has taught for a good many years, ideas borrowed from books, picked up in conversation, and originated in one's own brain, get at last hopelessly mixed up together in a kind of mental conglomerate. Not seldom also a teacher recognizes in the writings of a former pupil a flower the seed of which was sown in his own lecture room. Of this he cannot complain, for it is one of his highest rewards. A teacher does not and should not claim any copyright in his thoughts: he is doing his duty best when he drops each conception of his own mind, as it is duly ripened, into the receptive mental soil of his abler students, there to germinate and bear fruit, perhaps better than on the exhausted arable field of his own weary brain. So I may be sometimes suspected of plagiary when it is really from myself; and if in these pages any geologist recognizes ideas of his own, used without acknowledgment, I crave his pardon, and trust to the liberality of true men of science. We borrow and we give: "*Hanc veniam petimusque damusque vicissim.*"

It may be well to observe that I have excluded from this book a few topics on the ground of their being either too technical to be made intelligible to the general reader or at present too uncertain in their bearing on the subject to be of any real service to him. As a rule, I have confined myself to the more important questions (as they seemed to me), and have set forth the views which are the more generally entertained. Still I have not thought it needful entirely to sink my own individuality, and on one or two points have expressed opinions which, just at the present time, are those of the minority (though a large one) rather than of the majority of geologists. As my excuse for so doing, I must plead that these questions for many years have been to me subjects of special study, and that in regard to them I have had rather exceptional

opportunities of forming an opinion. Chief of these are—the physical geography of Britain in the earlier part of the Triassic period, the effects and former extent of glaciers, and the history and age of certain crystalline rocks. The last question, which is one of great interest and far-reaching importance, practically indicates my position in regard to the "Uniformitarian creed" in geology, and the one matter on which a slight difference in opinion from the revered author of "The Principles" will be perceptible. To "Catastrophical geology" I am no less opposed than were our great masters Hutton and Lyell. I fully accept the leading principles of Uniformitarian geology, but I cannot close my ears to the conclusions of men eminent in experimental and mathematical physics, or insist on regarding "the universe as a self-winding clock." Nay, I venture to think that even in the earth itself we can discover, by processes strictly inductive, some sign of its beginning and some foreshadowing of its end.

I hope that no serious errors are lurking in these pages; but geology has now become so vast a subject that perfection in all its branches would almost be another name for scientific omniscience; and nothing makes one so conscious of the truth of the saying, *Humanum est errare*, as writing a book. Besides the errors due to the author's own ignorance or to the unaccountable freaks and perversities of his memory, there are those typographical mistakes which so often contrive to elude his notice as to tempt him to believe that beings not wholly beneficent haunt the precincts of the printing office. If errors prove to be few in number, this is largely due to the kind assistance which I have received in the revision of the proofs from Miss C. A. Raisin, B. Sc., a former pupil and now frequent helper in scientific work, to whom I tender my most grateful thanks. These also are due to the authors, scientific societies, and publishers, hereafter more particularly enumerated, who have permitted the use of illustrations which were their property.

The study of geology has added much to the happiness of my own life; it has taught me to appreciate more fully the beauties and the marvels of Nature; it has often restored me, when weary and jaded, to bodily health; it has helped me in bearing those trials which are the common lot; if, then, this book is so fortunate as to interest others in the subject, I shall count that a high reward.

T. G. BONNEY.

UNIVERSITY COLLEGE, LONDON, 1893.

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NOTE.—The publishers desire to express their thanks to Mr. Murray for his kindness in granting them permission to include Figs. 30 and 31, from Lyell's "Principles of Geology"; to Messrs. Macmillan for the use of Fig. 75 from "The Voyage of the *Challenger*," and for Figs. 78 and 79, from Captain Wharton's paper in *Nature*; to Messrs. Bell & Son for the use of Figs. 12, 24, 25, and 41. To the Royal Society they are indebted for the use of Figs. 99, 100, and 101; Mr. Whymper has also been good enough to lend two blocks (Figs. 102 and 103) from his "Travels in the Great Andes"; and to the Council of the Geological Society they are indebted for Figs. 38, 115, 116, 51 (Spencer), 136 and 140 (Whitaker), 138 (Sir A. Geikie), 139 and 141 (Prestwich); while for permission to include Fig. 149 they have to thank the editor of *Natural Science*. Figs. 12, 58, 59, 62, 84, 85, 105, 124, and 131 are from sketches by the author.

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PART I.

THE STORY: ITS BOOKS AND THEIR SPEECH.

THE STORY OF OUR PLANET.

CHAPTER I.

INTRODUCTORY.

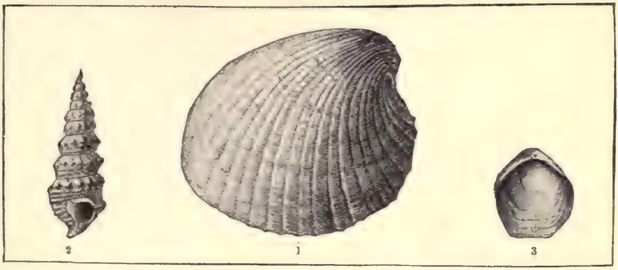

FIG. 1.—(1) *Cardita planicosta* (Upper Eocene); (2) *Melania inquinata* (Lower Eocene); (3) *Terebratula semiglobosa* (Chalk). All about half natural size.

THESE drawings represent three specimens, taken almost haphazard, from a collection of fossils. Each of them, beyond all doubt, once must have been part of a living creature. The first was dug out of a sandy clay, between high- and low-water mark, at a place called Bracklesham, on the Sussex coast. What of that? it may be asked; what wonder at finding a seashell in such a position? This only: that nothing exactly resembling it could now be discovered alive in British seas—or, indeed, in any other seas. Yet it was formerly common enough, for dozens of similar specimens could have been picked up where it was lying. But more than this: many other shells were abundant in that clay, not one of which is now to be found in British waters. Indeed, we notice on closer study that they are more like the shells which come from shores much nearer to the equator than those of our islands. Evidently it is many a long year since their tenants died. Every trace of ornamental coloring has disappeared; all the specimens have become of a uniform gray tint. They have lost the animal matter

which strengthens the shell of the living creature; all are more or less brittle—some break almost at a touch. So it seems reasonable to infer that since these mollusks lived and died the climate of Britain has greatly altered.

The next fossil came from a dark bedded mud in the Thames valley, which also was crowded with various kinds of shells, all extinct species, all bearing more resemblance to those which now inhabit warmer regions than Britain. The animals which, at the present day, are more nearly related to them live in rivers, especially where these begin to broaden out into estuaries. So far, then, there is nothing surprising in finding such fossils in the valley of the Thames, some three or four leagues below the port of London. But the clay in which they were lying is at least fifty feet above the present level of the river, and was evidently deposited, as may be seen on closer examination, by a broader and grander stream than now glides below the slopes of Richmond Hill and under the bridges of London. The first specimen indicated a change in the tenants of this part of the globe and suggested a change in climate. This one not only gives confirmatory evidence, but also intimates that the physical geography of the district must have been considerably altered.

Let the third specimen now tell its tale. Like the others, it does not represent any creature actually living, though kindred forms are not uncommon, and it can be referred, like them, to a well-known genus. All three, however, are best represented, and may be said to be at home, in distant seas. But this specimen was obtained in a pit on the slopes of the Downs, some five hundred feet above the present sea level. Yet more, if we minutely examine the pure white chalk in which this shell was embedded, if we separate it carefully particle from particle, and place the dust, properly mounted, under a microscope, we shall find that not a little of this apparently formless powder has once been part of a living organism, which can be often identified with some tiny creature, a tenant of the open ocean far away from shore. So this last specimen carries us yet a step further than the other two. They intimate both a change in climate and geographical conditions not wholly identical with the present; this tells of a time when, instead of a green sward, dark spotted with old yew trees, instead of trailing hops and golden corn, a waste of salt waters extended far and wide, and the sea lay deep where now the Kentish Downs overlook the Sussex Weald.

Is it, however, possible to find any other explanation of the occurrence of these shells which might enable us to avoid conclusions so startling? At first men were content to regard them as freaks of Nature—mere imitative shapes, like the "birds' heads" and other "curiosities" which are sometimes brought to the geologist by ignorant folk in country places. But, as a closer study showed, the resemblance was too perfect: for these objects copied

FIG. 2.—CHALK OF GRAVESEND.
Showing foraminifera, with sponge spicules. (Much magnified.)

not only the external form, but also the internal structure of shell or of bone; and it became clear at last that the remains of the creatures which had been dead but a few years or centuries could be linked on, by imperceptible gradations, to those which were embedded in the solid rock, and had been subjected to great mineral change.

By some persons fossils were formerly explained as the results of a "plastic force" in Nature; preliminary and abortive efforts to produce the more perfect form—very much as when, according to Burns,

> Her 'prentice han' she tried on man,
> An' then she made the lasses, O !

But such an explanation obviously was no better than a mental stop-gap, like the answers with which parents not too learned try to satisfy inquisitive children. It failed to content men who wanted to get at the truth of things. They set about to devise a more rational account of this strange phenomenon. Then a simple way out of the difficulty seemed to present itself. They believed that, as related in the Hebrew Scriptures and affirmed by the traditions of many nations, there was once a great deluge, when the whole world was overspread by water. By this the spoils of the deep were supposed to have been scattered on the mountain sides, and thus the tale of the flood is inscribed on the records of the rocks.

For a while this explanation seemed satisfactory. But it, too, has been tried and found wanting. Had these dead and gone organisms been found only on the surface of the ground, or in the mud and gravel which are plastered here and there upon the hard rocks, it might have been possible—though there would have been other and more serious difficulties—to account for them by the surge and ebb of such a mass of water; but fossils may be traced through masses of rock far downward, they may be struck in borings, or brought up from shafts at depths of hundreds of feet below the surface. A more extended study and an attempt to classify the results of the collector's patient searching speedily disclose the fact that particular groups of fossils are characteristic of certain localities—that they are not huddled together pell-mell, but occur in such regular association that if one or two well-known forms are picked up on entering a quarry it can be predicted, after a little experience, what is likely to be discovered on a further search. Another generalization soon follows. Different kinds of rock are seen to lie one upon another, like a number of volumes which are placed either flat upon the table or resting on a slope. It is observed that each of these rock beds contains a different group of fossils: each volume has its own set of pictures, telling the tale of an epoch in the history of life. When the scope of our observations is extended, and any one of these rock masses is traced from district to district, as it appears at the surface, we find that although some changes take place in the fossils contained—just as, at the present day, differences can be observed in the vegetation of the land or in the tenants of the sea, as the coasts of a continent are followed from east to west, or still more from north to south—nevertheless the rock mass can be identified in regions widely separated. As in the annals of bygone nations connecting

links are found by which the historian can distinguish corresponding epochs, so is it in the records of the rocks, when the tale is told by these "medals of creation," as they have been not inaptly named. This, however, is not all. Suppose that, in any district of England, three masses of rock occur, each of which is characterized by a distinctive group of fossils. Let these be denoted, for simplicity of reference, as A, B, C, and let A represent the highest and C the lowest mass—which means, naturally, that C is the oldest and A is the newest of the three. Suppose, then, that the same three groups of fossils are discovered in some other country—such as in Belgium or in one of the more distant parts of France—they will always occur in the order A, B, C; never in any other. It is not, indeed, necessary that all should occur: B may be missing. But then A will overlie C, and a careful examination will show that it does not follow immediately—that there is a distinct gap in the record—that a page, so to say, has been torn out of the volume. The principle of regular sequence thus indicated is found, on further investigation, to hold good universally, so that it can be enunciated as a general law that the order of succession among extinct creatures which has been established in one region of the earth is true for all.

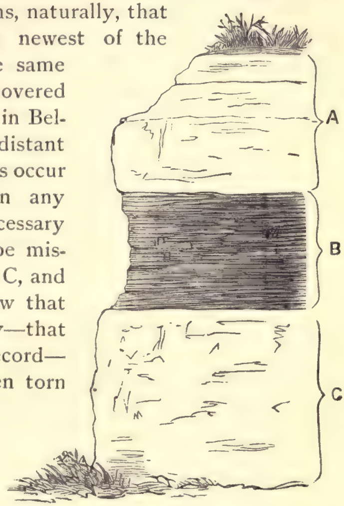

FIG. 3.—SEQUENCE OF MASSES OF ROCK.

As this is so—as the life-history of the past runs in a regular series, chapter by chapter—the attempt to satisfy inquiries by the assertion that fossils are the relics of a universal deluge is soon proved to be futile. No such catastrophe, even if the language of poetry be regarded as sober prose, could explain the vast abundance of fossils, and their occurrence in a definite order in masses of rock the thickness of which can be measured by thousands of feet. Gaps there may be in the record, interruptions here or there to its continuity, difficulties in harmonizing every detail, or in bringing the annals of different countries into perfect parallelism. Such exist also in the history of our own race, and they become

more frequent as we approach the twilight of the dawn; but in the one case, as in the other, patient research and careful induction have been not without their due reward, and many a page in the chronicles of the earth, no less than in the annals of nations, has been already deciphered.

This is the history which we must try to tell; our task it is to give some idea of the processes by which the earth has been molded and shaped into the stage on which all the tragedy and all the comedy of human life have been enacted. So, as we have to tell the story of our planet, a few words at the outset must be said about the earth as a planet—that is, as to its form, mass, and its position in the solar system. The earth is a globe. The question of its form has been so thoroughly threshed out that, though a few advocates of a contrary opinion have existed within the memory of man, possibly may still linger—for what crotchet, what mental fungus, cannot find a congenial soil in the present age?—it is needless to repeat the proof which every text-book contains. The earth, however, is not a perfect sphere. Apart from the minor inequalities of its surface, its form is more nearly that of a spheroid of revolution—the figure generated by an ellipse revolving about its shorter axis. The difference, however, is not great—the polar diameter of the earth measuring 7,899.37 miles, the equatorial 7,925.82 miles. Thus the greatest thickness of the equatorial protuberance, as it is called, of the bulging mass which distinguishes our globe from a perfect sphere, is just under 13¼ miles, which, however, is considerably more than twice the height of the loftiest peak upon the world's surface.

The earth moves in an orbit about the sun at a pace which far exceeds that of the quickest express—no less than 19 miles a second. It rotates, at the same time, about its polar diameter, making one complete turn in 23 hours 56 minutes 4 seconds. During this period it has changed its position in the orbit, so that in order to bring any place on the globe into exactly the same position with regard to the sun, a little more turning is required, and the day, thus measured, consists of 24 hours. After having turned 366 times on its axis, and having been illuminated 365 times by the sun, the earth has come back to the same position in its orbit, and a solar year has been completed. But the diameter of the earth, about which it revolves, is not at right angles to the plane of the orbit—it is inclined at an angle of 23° 28′ (nearly). This, as is well known, produces the summer and winter seasons and the variation

in the length of day and night. The orbit is an ellipse, and the sun is placed, not at the center, but in one of the foci. Thus the distance of the earth from the sun is not always the same; indeed it changes not only at different times of the year, but also from year to year, though very slowly. At present when the earth is nearest to the sun the distance is 91,100,000 miles; when it is furthest away this attains to 94,600,000 miles: the average or mean distance is reckoned as 92,700,000 miles. The mind can hardly grasp the notion of distances so vast; we can appreciate them better if we remember that light itself takes eight minutes and sixteen seconds in traveling from the sun to the earth, and that were it possible for sound to travel so far, before the cry of a newborn babe could reach the sun the child would be fifteen years old.

The earth, as we all know, has an attendant satellite—the moon—a globe about 2160 miles in diameter. This revolves about the earth as it does about the sun, at a distance of 238,793 miles, completing a revolution in a period of 27¼ days; it rotates upon its axis in the same amount of time, so as to present always the same face to the earth. But the earth is only one of a number of planets which revolve in like way about the sun. Of these, two are nearer neighbors than our globe; five are further away. They differ from the earth in size and in other respects. The planet nearest to the sun is called Mercury,* which has a diameter of 2992 miles; next comes Venus, which has a diameter of 7660 miles, and so is very nearly the size of our own planet. More distant than the latter from the sun is Mars; it has a diameter of 4200 miles, and is attended by two moons, which, however, complete their journey round it in a much shorter time than our own satellite. Jupiter is next in order†—a huge mass, 85,000 miles in apparent diameter—attended by five moons, one of which, however, is very tiny. Saturn comes next, accompanied by eight satellites, and distinguished by a ring, triple in structure and a hundred miles in thickness. This planet is somewhat smaller than Jupiter, for its diameter is 71,000 miles. The next planet, Uranus, is attended by four moons, but it is considerably smaller than Saturn, its diameter being about 32,000 miles. The series is closed by Neptune, which

* Some astronomers are of opinion that a small planet has been detected between Mercury and the sun. Its existence, however, cannot be regarded as proved; indeed, many attach little value to the evidence which has been adduced.

† In the interval comes a group of planetary bodies, comparatively small in size, called the asteroids. It has been suggested by some astronomers that they may be the ruins of a single large planet.

is nearly the same size as Uranus, having a diameter of 34,500 miles. It has at least one satellite.*

It would be easy to cite the distances of each of these planets from the sun, but, as we have already said, the mind can hardly appreciate millions of miles: a clearer notion can be gathered from an illustration which many years since was given by a famous astronomer, Sir John Herschel. In the middle of a wide and level

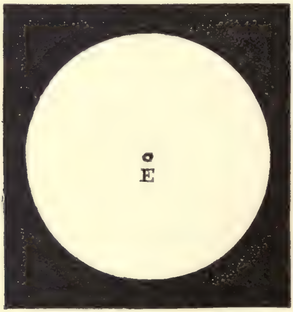

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FIG. 4.—COMPARATIVE SIZE OF THE SUN (S) AND THE EARTH (E).

plain, place a globe 2 feet in diameter. Take this to represent the sun. From it, as a center, suppose a circle† drawn with a radius of 82 feet, and a grain of mustard seed laid upon any part of the curve. These represent Mercury and its orbit. Draw another circle, with a radius of 142 feet, and on it put a pea. That is Venus. Draw a third circle, with a radius of 215 feet, and put theron another pea. That is the earth. On a fourth circle, with a radius of 327 feet, lay the head of a large pin. That may represent the planet Mars. Now a long interval must be left, but this, in order to give a complete representation of the solar system, should be interrupted by a number of circles, with radii varying from 500 to 600 feet, on each of which a grain of sand is laid; these would stand for the asteroids. Then, at a distance of nearly a quarter of a mile from the model of the sun, draw a circle, and

* Authorities are by no means in complete accord as to the numbers given in the above paragraph, so that those quoted must be regarded as approximate.

† The planetary orbits are ellipses, but as the scale is so small, the error in representing them by circles is almost inappreciable.

place on it a moderate-sized orange. This is Jupiter. The next circle must have a radius of two-fifths of a mile, and Saturn may be indicated by a fairly large "tangerine." Lastly, small plums may serve to represent Uranus and Neptune, and for each circles must be drawn, the one with a radius measuring three-fourths of a mile, the other with a radius of as much as 1¼ mile.

The weight of the earth as a whole is between five and six times as great* as if it consisted throughout of water, supposing the fluid to be incompressible. Of the other planets some are heavier, some lighter, bulk for bulk, than the earth. The four great bodies appear to be formed of material comparatively light; but the weight of this may be somewhat underestimated, because observers, in calculating the size of the planet, may have failed to distinguish between its actual globe and the denser portions of its atmosphere. Into these questions, however, it is needless to enter, since they have no direct connection with the history of our own planet.

The solid earth, as everyone knows, is incompletely covered by a shell of water, which also traverses the dry land in streams, and sometimes spots its surface with lakes. A gaseous envelope surrounds the whole—namely, the air which we breathe. Thus the history of our planet, if the problem be completely investigated, must be studied in each of these three regions; for though ocean and air may be small in volume compared with the solid globe, though their effects upon it at any great depth may be insignificant, yet upon its surface they are all potent, and it is with this that man is mainly concerned, for, after all, he is but as a parasite on its cuticle.

* The specific gravity of the earth is about 5.6; that of iron is 7.4; that of magnetite or hematite (common ores of iron), 4.8. So the earth is rather heavier, bulk for bulk, than these ores.

CHAPTER II.

THE LAND REGION.

THE land is man's natural abode, so it shall be described first, though it occupies only about three-tenths of the surface of the globe, for the area of dry land is, roughly, 55,000,000 square miles; of the ocean, 137,200,000. Taking the mean level of the ocean as a plane of measurement, we find that its average depth much exceeds the average height of the land. It has been estimated that the latter amounts to 2252 feet, or a little more than 375 fathoms—that is, the height of the uniform plateau which would be formed if every mountain chain were dug down and the materials were spread out over the lowlands—if the two processes of leveling up and leveling down were employed till all inequalities had disappeared, and the earth's surface had attained to the Socialistic ideal. Though the summits of mountain chains reach a much greater elevation, though peaks in the Andes surpass 20,000 feet, and the icy crown of Mount Everest, the king of the Himalayas, even rises to 29,000 feet above the sea, yet the greater part of the dry land, as it now exists, lies comparatively low, 84 per cent. of the whole surface being less than 6000 feet—a thousand fathoms—above sea level. To one who has gazed at the giant peaks of the Alps, as they tower on high above the lowlands of Switzerland or the plains of Northern Italy, this statement may seem almost incredible, but it is affirmed that if the whole mass of the Alpine chain were spread out over Europe alone it would not increase the elevation of that continent by more than 22 feet. The average depth of the depression occupied by the ocean is 14,640 feet; this is nearly equal to the height which the Matterhorn, so familiar to most Alpine travelers, attains above its surface. Less than half the ocean bed (42 per cent.) lies within soundings of a thousand fathoms, and an appreciable portion (about 2 per cent.) exceeds 3000 fathoms, the greatest known depth being 4655 fathoms, or about a thousand feet less than the height of the loftiest mountain peak

above it. If the waters of the ocean were gathered together into a solid mass they would form a globe about 850 miles in diameter.

Thus the depressions occupied by seas, as it is important to remember, are on a far grander scale than the mountain chains. The greatest height above the sea level and the greatest depth below it are nearly equal, but if we drew two contour lines on a large globe—one a thousand fathoms above, another a thousand fathoms below sea level—less than 1½ per cent. of the whole surface would lie above the former, and nearly 22½ per cent. below the latter; in other words, an ocean basin is a physical feature on the earth's crust of much more significance than any continental elevation.

Both, however—and this is no less important to remember—are inequalities almost trifling when compared with the whole mass of the globe. To the crawling caterpillar the molehill seems a mountain; to the limited vision of man that wall of snowclad peaks which bars his horizon from the ramparts of Berne or from the battlements of the Duomo in Milan seems of stupendous vastness. Some scale more comprehensible by our senses must be adopted in order to dispel the glamour of crag and glacier. Suppose, then, that a globe has been constructed with a diameter of a hundred feet, which is, roughly, equal to that of the dome of St. Paul's Cathedral, and that on its surface the mountains of the earth have been modeled, and the depths of the ocean have been excavated, in each case on a true scale. Then the peak of Mont Blanc would rise less than half an inch above the original level, the summit of Mount Everest itself would be not quite nine-tenths of an inch above it, and the ocean would be lodged in a shallow depression, much of which would vary from half an inch to an inch in depth. But, as perhaps even the dome of St. Paul's may be rather too large an object for our mental gasp, let us take a globe, such as is commonly sold, two feet in diameter. Suppose that the attempt be made to model on its surface the mountain chains and the ocean depths of the earth. On such a scale the summit of the highest peak will be represented by a thickness of about seventeen-thousandths of an inch—that is to say, the difference between the greatest height above and the greatest depth below the sea level will be represented roughly by about three-hundredths of an inch. All the inequalities of the land surface would have to be sculptured in the thickness of an ordinary playing card. So we can realize that the greatest of these—the loftiest mountain peak or the pro-

FIG. 5—THE ALPS, FROM BERNE.

foundest depth of ocean—are insignificant compared with the earth's mass as a whole; that no change in the position of land and of water, no replacement of seas by mountain chains, of continents by oceans, is likely to produce any material effect upon the stability of the earth's axis of rotation.

Certain peculiarities in the forms of the existing continents and in the distribution of the seas can be more conveniently discussed in later chapters, but one or two others may be mentioned in passing. The more distinctly elevated lands—in other words, the mountain regions—are commonly restricted to comparatively narrow belts on the earth's surface, and rise with some steepness from the lower ground. The Alps, for instance, occupy a zone from a hundred to a hundred and twenty miles in breadth. As the highest peaks do not quite attain to an elevation of three miles vertical, the average slope cannot exceed one in twenty, and is generally less. The crest, however, of a chain seldom corresponds exactly with the middle line of the tract which it covers, so that the average steepness of one slope generally exceeds that of the other. Thus the gradient on the western side of the Andes is said to be one in forty, but on the other it is less than one-half this amount, or one in eighty-three.

A linear group of mountains forms a range; two or more parallel ranges in close connection constitute a chain. Isolated mountains of any importance are comparatively rare, and when they occur are generally volcanic—that is, are gigantic heaps of ash and slag piled up around some orifice in the crust of the earth. Sometimes, however, hills, and even mountains, of "circumdenudation" may be found—isolated fragments of far larger masses of rock, the rest of which has been removed, as will be hereafter explained, by the carving tools of Nature. A marked instance of such a mountain is Roraima, in British Guiana, an insulated mass which rises precipitously above the tropical forests, like some vast hill-fortress, to a height of about 7500 feet.

Almost every part of an important land mass, as might be anticipated, is above the level of the sea, but a few localities may be found which are exceptions to this rule. Such are considerable portions of the Aralo-Caspian basin, which lie at various depths below the level of the ocean, amounting at most to a little over 80 feet. The lower part of the Jordan valley is a still more remarkable exception, for the whole course of that river, from the neighborhood of Lake Huleh downward, is below the Mediter-

ranean, the surface of which is almost 1300 feet above that of the Dead Sea.*

Before quitting for a time the subject of the dry land, one or two peculiarities in its distribution over the surface of the globe may be briefly noticed. The continental masses are mainly restricted to the northern hemisphere; they do not, however, appear to stand in any direct relation to its pole, except that in the regions adjoining this water apparently dominates over land. Recent discoveries in

FIG. 6.—A VOLCANIC HILL (VESUVIUS, FROM THE SEA).

the North of Greenland seem to demonstrate that it is a large island, the shores of which do not extend northward beyond about 82°. No great amount of continental land projects north of the seventieth parallel of latitude; Greenland, with the large islands to the west of it, Spitzbergen and Nova Zembla, are almost the only land areas of importance known to occur between that parallel and the North Pole. The contrary conditions probably prevail at the southern pole; this seems to be surrounded by a considerable mass of land which may come down in places to about the Antarctic Circle. But between its shore and the fortieth parallel of latitude

* The level of the Dead Sea varies about five feet, according to the season of the year; the average difference between it and the surface of the Mediterranean by the last measurement was 1292 feet.

very little land occurs, while in the northern hemisphere considerably less than half this zone is occupied by water. But the most marked contrast in the distribution of land and water is afforded by taking London as a pole, and dividing the globe into two hemispheres. The one around our metropolis includes almost the whole of the great continental masses, all Europe, Africa, and North America, almost all Asia, and far the greater part of South America. The other hemisphere contains only Australia and the Australasian Islands, a bit of the Malay peninsula, New Zealand, South America about as far as Buenos Ayres, with whatever land may surround the southern pole. It is also remarkable that the land masses exhibit a general tendency to become narrow toward the south, and to throw off peninsulas running in the same direction. In the case of three great land masses—Africa, South America, and Australia (if Tasmania be included)—it has been further observed that their pointed ends lie at about equal distances one from another on a circle, the normal to which makes an angle of 10° with the South Polar axis, and that another circle, similarly situated in regard to the North Pole, passes through most of the great inland seas and large lakes. It is possible that each of these regions may indicate zones of depression on the crust of the earth.

FIG. 7.—LAND HEMISPHERE.

Attention also may be called to another fact, the significance of which will be discussed in a later part of this volume—that a relation evidently exists between mountain chains and the beds of seas or oceans. This, on a comparatively small scale, is well exemplified in the Alps. The shallow basin of the Adriatic, with the plain of the Po, is bordered by the Apennines, the Alpine chain, and its prolongations, the Dinaric and Julian Alps. A depression of about two hundred feet would bring out a relationship yet more curious. Italy is often familiarly compared to a boot. By this change of level the likeness would be undisturbed, but the sea also would present the outline of a second boot, and thus complete the pair. The relationship, however, of mountains and oceans is not always

conspicuous where the continents are complicated in form, like Europe and Asia. In the case of the latter the enormous mountain mass, which radiates from the "roof of the world" (the Pamirs): the Hindukhush, with all the highlands of Afghanistan; the vast chains of the Himalayas, the Karakorams and the Kuen-lun, with the plateaus of Thibet, which themselves overtop most European peaks; the gigantic mass of the Thian Shan, with its prolongations; and the deserts of Eastern Turkestan and Gobi—these, indeed, cannot be brought into very close relation with the Indian or the Pacific oceans; but in the case of the three more simply formed continents—North America, South America, and Africa—no such difficulty exists. In all these the important mountain chains border the oceans, and the grander chains rise near the margins of the greater oceans. Compare, in North America, the Appalachians, on the Atlantic border, with the vast composite mountain mass which runs parallel with the Pacific from one end of the continent to the other. The same is true of South America. Much high ground, no doubt, exists near the Atlantic coast, especially in Brazil, but this is dwarfed by the towering volcanic summits of the Andes, many of which overtop Mont Blanc, in some cases by more than five thousand feet. The main watershed of the country lies far away to the west; from its crest the ground on that side may be said, with little exaggeration, to plunge down to the sea, while from its other flank the great rivers flow to the Atlantic almost across the continent. Africa exhibits the same characteristic of mountains running parallel with the coast; but as the Indian Ocean and the Atlantic are more nearly equal in importance, the two groups of chains differ less, and the general structure of the country, probably owing to other causes, exhibits more complications. But the relation of continental masses and ocean basins involves many questions of extreme difficulty, and even an attempt to discuss it must be postponed to a later occasion. At present it may suffice to observe that extensive basins of inland drainage—that is to say, areas from which there is no outflow to

FIG. 8.—OCEAN HEMISPHERE.

the ocean—are by no means rare on some of the continents. There is, among others, the neighborhood of Lake Titicaca, in South America; the region between the Rocky Mountains and the Sierra Nevada, including the Great Basin of Utah, in North America; the districts around Lake Tchad and Lake Ngami, in Africa; and extensive tracts in Australia. No such basins occur in Europe, but they abound in Asia. Not only are there the districts of the Dead Sea, the Aral, and the Caspian—parts of which, as already said, are actually below the sea level—but there are vast regions above it, sometimes at great altitudes; such are lakes Van and Urmia, the Plateau of Iran, and the Mongolian Desert, with Eastern Turkestan and Western Thibet, the last forming a rudely rhombic area, perhaps as large as European Russia.

The crust or solid external part of the earth is composed of minerals. A mass of minerals, whether it consists of several or of one only (commonly the former), is called a rock. With this word an idea of coherence and solidity is popularly associated, but in geology that is not so. The material of a Lancashire sand hill and that of the cliffs of Snowdon are equally rock, in the scientific sense of the word, and in this sense it will be used in the following pages. Hereafter something will be said about the history of rocks and the modes in which they have been formed; at present a few words may suffice in explanation of certain terms which it will be needful to employ occasionally in the earlier part of this book.

Rocks may be divided into two principal groups: those which have solidified from a fused condition, and those formed of constituents more or less gradually deposited. The former are called igneous rocks; they vary in mineral composition and in texture. Most of them are more or less distinctly crystalline—that is to say, are composed of individual minerals, which have gradually segregated out of the molten mass—but in some a crystalline structure is practically not to be distinguished. Granite is an example of the former kind, felstone of the latter; some, however, like obsidian, are true glasses. Yet these three rocks may contain the same constituents in the same proportions—may be chemically identical. The differences between them are due to their environment, to the circumstances under which they have cooled. When the loss of heat has been rapid the rock is glassy, and often porous or slaggy. With a more gradual fall in temperature, the mass assumes a more solid and more crystalline condition.

As the rocks in the second group are almost always deposited,

more or less directly, by the action of water, they are concisely designated "aqueous rocks," though a few—such as blown sands and the piles of dust and lapilli ejected from volcanoes—have been transported by wind instead of water. Still as it may be argued that air at any rate is a fluid, and that in many cases steam rather than wind has caused an accumulation of volcanic ashes—for the fragments may lie as they fell about the crater after an explosion—no misapprehension of importance is likely to be caused by the extended use of the term. Aqueous rocks may be subdivided into (1) those which have been precipitated from solution in water—such as rock salt, gypsum, and travertine; (2) those which have

FIG. 9.—BLOCK OF PUDDING STONE.

been deposited by water as fragments broken originally from other rocks—such as gravel, pudding stone, sandstone, clay, and shale; and (3) those which are composed wholly, or almost wholly, of the remains of organisms (generally accumulated in or under water)—such as peat, coal, tripoli, chalk, and the purer limestones. It must be remembered that these sedimentary rocks, as they are not seldom called, cannot always be separated by hard and fast lines, because they may have been formed by more than one of the above processes. Mud or sand may be carried into a sea, and may settle down to mingle with the relics of the creatures which have lived on its floor or have tenanted its waters. Precipitation of mineral substances may go on together with the accumulation of sediment or of dead organisms; so that, as a rule, terms like sandstone, mudstone, and limestone, indicative of sedimentary rocks, cannot be used with extreme precision.

Most rocks which have been deposited for a very long time have undergone some mineral change—the hard limestone was once a

soft ooze, the best honestone once a mud—but there are some masses which have been so greatly altered that it is often no easy task—and is sometimes almost impossible—to determine what has been their original condition. Rocks in which such marked alterations have taken place are called metamorphic, and these are gener-

FIG. 10.—STRATIFIED ROCKS.

The dark line running down the face of the cliff in front is called a fault: the mass to the right of it has dropped down. This has preserved the bed *h*, which has been removed by denudation from the opposite side of the fault.

ally treated as a separate or third group. Of such, mica-schist, quartzite, serpentine, and statuary marble are examples.

In sedimentary rocks, as might be expected, their origin is indicated by their structure. The materials, when fine, form thin layers, and the rocks are then said to be laminated. So long as these continue without variation in size the rock mass increases without any change. Its character is altered when the fragments become larger or smaller; a layer thus distinguished from that immediately above and below is called a *stratum*, and rocks formed of such layers are said to be stratified. Lamination, indeed, is a record of some very slight check or change in the deposit of materials; stratification indicates more marked instances of the

same. A stratum is related to its laminæ somewhat as a book to its leaves. Sometimes stratification can only be detected on a close examination; sometimes the layers are as distinct as are a number of mattresses when laid in order one on another. Fine-grained rocks of an almost homogeneous or a laminated character,

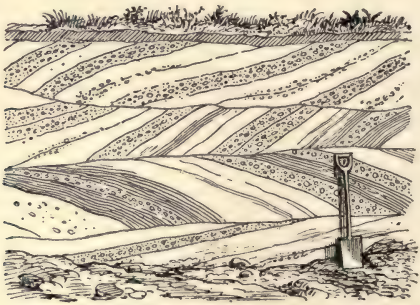


FIG. 11.—A CASE OF FALSE BEDDING.

like muds and shales, indicate quiet deposit; irregularities of structure are records of stronger and more variable currents. The sand on the shore or beneath the shallower water is thrown into gentle undulations by the movement of the waves or by the action of currents, whether in the air or the water. Similar structures can be seen in such rocks as the finer sandstones, and are called ripple-mark. Strong and variable currents, like those of a tolerably swift river, deposit coarser materials, which form shoal-like banks composed of sloping zones of more pebbly and of more sandy stuff. As portions of these are often destroyed by changes in the direction and the velocity of the currents—the tops of the banks especially being planed away—and as new shoals are formed in rather different positions, a mass of material thus accumulated, when it is cut through in a vertical direction, exhibits a double structure, the one, that on the smaller scale, being indicative of the building up of the several shoals, the other, that on the larger, being a record of the actual shoals (Fig. 11). As the former often appeals more quickly to the eye, especially when only a limited section is exposed, and would produce a misapprehension as to the angle at

which the stratum was inclined to the horizon, the structure is called false bedding. Some geologists use current bedding as an equivalent term; by others the latter is applied to instances where the structure is more regular.

Certain structures, called "joints," are almost always exhibited by the igneous or unstratified rocks as well as by the stratified.

FIG. 12.—JOINTS EXHIBITED IN A MOUNTAIN RUIN, FROM THE DOLOMITES OF CORTINA, S.E. TYROL.

These are divisional planes separating the mass into blocks. The latter may be large or small, regular or irregular in form, largeness and regularity commonly going together. In such a case stratified rocks are generally traversed by two sets of joints at right angles one to another and to the planes of bedding (Fig. 12); igneous rocks by three, so as to form rectangular prisms. In these rocks four sets of joints may be sometimes found, forming hexagonal prisms (Fig. 13).* This is the normal shape, but occasionally the

* This is often called "columnar jointing," sometimes "basaltic jointing." The latter is a misnomer, for the structure is not restricted to basalt, but is found in other fine-grained igneous rocks. It has been observed also in sedimentary rocks, but here it is generally the result of heat, and the prisms commonly are small, less than three inches in diameter. A remarkable instance in a volcanic mud, over which a lava stream has passed, may be seen in Tideswell Dale, Derbyshire. It can be produced artificially, but is then generally quite minute.

number of sides is greater or less than six. The grand colonnades of dark basalt at the Giant's Causeway, in Antrim, and about Fingal's Cave, in Staffa, are striking examples of this mode of jointing (Fig. 14). In the Siebengebirge the basalt columns are so long and slender as to be used for fingerposts and like purposes. Joint structures were helpful to man in his first efforts at monumental architecture. By their regularity, but comparative infrequency in some varieties of granite, the huge roof of the dolmen of Concarneau, and the great menhir of Lokmariaker, were rendered possible,

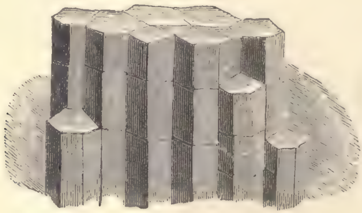


FIG. 13.—COLUMNAR JOINTING.

no less than the pillars of the Pantheon at Rome, and the yet vaster masses of the Egyptian obelisks.

Other structures there are which in due course may receive further notice. For the present it may suffice to say that many rocks are affected by a tendency to split in a direction which has no necessary connection with their original bedding. This is most perfect and conspicuous in rocks composed of very fine materials. Such are called slates, and the structure is named slaty cleavage. But it may be seen also in rocks of coarser grain, though in them it is much less uniform and regular. Indeed, it has been sometimes impressed upon igneous rocks, as may be often seen in mountain regions. Formerly the cause of this structure was much disputed; that it is a result of pressure is now generally admitted.

Thus the crust of the earth, as the most casual examination indicates, is composed of masses variable in form and of materials heterogeneous in character. It is like some colossal structure, in the architecture of which diverse substances have been employed and different modes of building adopted. So when this crust is attacked by the various forces of Nature—the heat and the cold, the wind and the rain, the stream and the wave—it offers an

unequal resistance. As it falls into ruins the varied constructions are revealed, as in buildings made by the hand of man, and every shape of crag or sweep of slope, every outline of peak or curve of valley, is due to the character of the materials and to the structures of each particular portion of the earth's crust.

FIG. 14.—COLUMNAR BASALT, FINGAL'S CAVE.

CHAPTER III.

THE AIR REGION.

THROUGH the air man moves; by it he is ever surrounded; on it his life depends, even more immediately than on water; so this region, often termed the atmosphere, seems to claim priority of notice to that of water. It differs from the ocean in covering the whole globe, extending to a height of at least two hundred miles above the surface of the latter; but as it rapidly decreases in density, and at last becomes exceedingly thin, its outer limit cannot be ascertained. As air has weight, the atmosphere exercises a pressure upon the surface of the earth and everything thereon, amounting to about fourteen pounds on the square inch. So the weight of the atmosphere is equal, roughly, to that of a shell inclosing the globe, which, if made of water, would be 30 feet thick, or if of an average kind of rock rather more than 13 feet thick.

Air consists of nitrogen and oxygen gases in the proportion of 79 to 21.* Either of these by itself would quickly put an end to life; thus mixed they are essential to its continuance. Small and variable quantities of water vapor and of carbonic acid gas are also present—the former of these, on an average, amounts to about 0.45 per cent.; the latter to much less, only from three- to five-hundredths. Occasionally other gases—such as sulphuric acid—are locally present; these, however, may be regarded as accidental, resulting from such causes as the presence of large towns and other irritations of the earth's cuticle for which man is responsible.

The aqueous vapor not only is the immediate source of rain, but also performs another function of the utmost importance. Though the interior of the earth is at a high temperature, the internal heat escapes so slowly that it does not appreciably affect the surface. This is warmed by the sun. The rays of light and heat from that gigantic furnace traverse space without appreciably raising its

* The proportions of dry air, neglecting the slight and mostly unmeasurable traces of the other constituents, may be put as follows: Oxygen, 20.95; nitrogen, 79.02: and carbonic acid, 0.03 parts to 100 by volume.—Ferrel, "A Popular Treatise on the Winds," p. 1.

temperature, which is probably as low as − 239° F. If the day come, as in the poet's vision, when "the sun itself shall die," the earth, supposing the extinction to be sudden, would quickly cool down, as a stone does if removed from the full glare of the midday orb into an icehouse; life would be impossible, our blood, lungs, heart, would be stone, for everything would be frozen solid. If there were no aqueous vapor in the atmosphere, considerable risk would attend even the temporary withdrawal of the sun's heat during the night time; for as it is, this, as everyone knows, causes a marked fall in the temperature. The air alone would avail but little to remedy the loss; it too, like the earth, would quickly radiate into outer space the store of heat accumulated during the day; but a safeguard is found in the small quantity of aqueous vapor so generally present in the atmosphere; for this, while fairly transparent to luminous heat, is opaque to radiant heat—that is to say, it allows vibrations emitted by the sun to pass without appreciable obstruction, but when the surface of the darkened earth begins to disperse its accumulated store, the passage of these slower vibrations is resisted. In other words, the aqueous vapor present in the atmosphere plays, as it has been well said, the part of a ratchet wheel in machinery. It is always found that the drier the climate the greater the difference between the highest reading of the thermometer by day and its lowest reading by night; and if all the aqueous vapor could be suddenly eliminated from the atmosphere, only for the interval of a summer night, the sun would rise next morning on a land petrified by frost.*

The aqueous vapor rapidly diminishes in quantity after a distance of a very few miles from the surface of the earth—the blanket, so to say, is wisely worn nearest to the skin. The density of the atmosphere also diminishes. At the sea level the mercurial barometer stands approximately at thirty inches.† At elevations above it the length of the column diminishes as the height of the station increases, the alteration amounting very roughly to rather less than an inch for every thousand feet of ascent. At the Great St. Ber-

* The atmosphere intercepts about four-tenths of the solar heat during the whole day, but only about one-quarter when the sun is in the zenith. The total amount of heat received by the earth from the sun in a year, if distributed uniformly over its surface, would suffice to melt a layer of ice 100 feet thick covering the whole earth.—Tyndall, "Heat as a Mode of Motion," ch. xiv.

† The average barometric pressure for all seasons and for all parts of the earth's surface is found from observation to be about 760 millimeters (29.92 inches).—Ferrel, p. 11.

nard Hospice, 8130 feet above the sea, the barometer stands at 22.2 inches; on Pike's Peak, 14,134 feet, at 17.7 inches; at the summit of Mont Blanc, 15,781 feet, nearly half the atmosphere by weight lies below the observer; and on the highest dome of Chimborazo, which is about 20,500 feet above the sea, Mr. Whymper on one occasion obtained a reading of 14.11, on another of 14.04 inches;* but in Messrs. Coxwell and Glaisher's highest ascent, at an elevation of 37,000 feet, the barometric reading was only 7 inches.

The question has been raised whether the rarity of the air on the summit of such a peak as Mount Everest might not prove fatal, and man meet with the death of a fish out of water.† Mr. Whymper's observations in the Andes of Ecuador showed that though exertion undoubtedly became more difficult, and a painful initiation had to be undergone in a region more than 16,000 feet above the sea, the vital powers were not seriously diminished even on the summit of Chimborazo.

But the height of the barometer—in other words, the pressure of the atmosphere—is not uniform at all places on the earth's surface; neither is it steady from day to day—even from hour to hour. The causes of these variations are complex—dependent on conditions general as well as local. As regards the former, the atmospheric pressure on the sea and in its immediate neighborhood is rather less over a zone about the equator than it is further to the north or south, a maximum being reached between latitudes 30° to 35°; the average reading is, in the one case, 29.84 inches, in the other, 30.08 inches. Then it diminishes slowly toward the poles, declining to about 29.92 inches in latitude 50°, so that beyond this there is a second low pressure area. The atmospheric pressure at the equator ought to be greater than at the poles, because a slight heaping up of the fluid above the former region must be caused by the rotation of the earth, but the abnormality indicated by the figures quoted above is possibly due to a variability in the amount of aqueous vapor in the atmosphere, by which its weight is

* Mr. Conway informs me (while this sheet is in the press) that the lowest reading which he obtained during his most interesting exploring expedition in the Karakoram chain was 13.30 inches. This, on comparison with a simultaneous reading at Leh, gives an altitude of 22,400 feet.

† Messrs. Coxwell and Glaisher nearly perished in a balloon at a height of about 37,000 feet. But as the change of level was rapid, this test proves only the height up to which life certainly can be continued.

affected.* The diurnal differences are the result of diverse causes, chief among which, in all probability, are the increase or decrease in the aqueous vapor and the rise or fall of temperature. In very dry countries, such as parts of Eastern Siberia, the barometer is said to rise by day as the temperature increases, and fall by night as it declines. The isobars also—or lines passing through the places on the earth's surface at which the barometer stands at the same height—exhibit a general correspondence with the diurnal isotherms, or lines indicating the same average daily temperature.

The winds are mainly produced by inequality of barometric pressure. Some are approximately constant in direction and permanent in duration; others are in action only during certain seasons; while a third set are more variable and brief, but sometimes more violent.

Of the first set the trade winds are the principal examples: vast currents of air of the utmost importance in the economy of the globe; the direct results of the sun's heat in the zone where its rays are most intense. Here, over a belt of variable breadth, which sometimes is little more than 150 miles wide, but sometimes is fully 600, the air, when the meridian sun is at or near the zenith, becoming heated, expands and rises. This—a region of light variable airs, inconstant in direction—is called the "zone of central calms."† But as the air rises, the equilibrium of the lower layers is disturbed; its place is taken by an inflow from either side of the belt. Thus a current is set up which affects a mass of air north and south of the equator. But this is so large that a marked effect on the direction of the wind is produced by the rotation of the earth. For instance, when air starts on a southward journey from latitude 25° N., it is moving eastward with the same velocity as this part of the earth's surface, but it passes on its course over places which are traveling at a much greater rate, and is thus, as it were, overtaken by them, and so, seemingly, comes from the east of north. When a steamer is crossing from Dublin to Holyhead, and the wind is blowing from the north, the smoke drifts toward the southwest, and this, to anyone unconscious of the vessel's motion, would indicate the direction of the wind. So in the region of the northern trades the breeze seems to come from the northeast. Similarly in that of the southern trades it apparently blows from the southeast.

* Professor Ferrel explains it as being due to a difference between the rate of rotation of the atmosphere and of the earth, which vanishes about latitude 30° N. and S.

† Also "the equatorial calm belt."

These currents of air flow, as a rule, with a steady and uniform motion, though disturbances are apt to be produced by the continental land masses; the regions, however, which are affected by them vary in breadth. This may amount to as much as thirty degrees of latitude in the South Pacific, but does not exceed twenty, and is sometimes not quite so much, in the North Atlantic.

The course of the air which has mounted up from the zone of central calms has yet to be traced. It wells up like the water of a continuous spring which girdles the globe. After a time the air, as is the case with water, ceases to rise, and flows northward and southward over the mass below. This, however, is traveling in the contrary direction to replace that which has risen, and its room must be occupied; so, as the upper current of air is cooled by radiation of its heat into outer space, it becomes heavier than the underlying mass, and slowly settles down to the earth. Obviously these currents on their journey northward and southward will be converted respectively into southwest and northwest winds. Thus a circulation of aërial currents in opposite directions—a kind of "endless cord" arrangement—is permanently established north and south of the equator, though the area affected does not remain exactly the same during the whole year. The belt of central calms must of course change its position in accordance with the apparent path of the sun, so that both it as well as the zones affected by the northern and southern trade winds must move backward and forward.* For instance, it is supposed that the northern anti- or counter-trades descend in winter about the latitude of Lisbon, at the equinoxes about that of Berlin, and in the summer they may come down even as far north as St. Petersburg. By their descent, as by their ascent, another zone of so-called calms is formed, though here the epithet is less strictly applicable, for it is rather one of shifting winds, variable in force, but commonly light. The division between these moving masses of air—which itself will be a zone of variable and uncertain airs, though apparently of no great vertical height—must obviously approach the earth's surface as the latitude increases. The lower current at first affects the air for a height of from four to five miles vertical, but before reaching latitude 30° N. its height has greatly diminished. An interesting illus-

* Professor Ferrel ("Popular Treatise on the Winds," p. 159) gives, for the N.E. trade wind, a table indicating the latitude at which it begins in the four seasons. The extreme difference between the summer and winter position is about 6°. According to another table, this, for the S.E. trade, amounts sometimes to 14°.

tration is afforded by the Peak of Teneriffe, which rises to a height of 12,060 feet above the Atlantic. At one season of the year the clouds, both on the summit and the zone about 3000 feet below it, move from the southwest, indicating that this rises into the region of the counter-trades, but those on the lower part of the mountain are driven by the trade wind from the opposite point of the compass. A curious proof of the existence of the counter-trade current has been afforded by the fine, almost impalpable, dust which is often shot up high into the air by the explosive force of a volcanic eruption. Such a dust shower fell at Barbadoes on a May morning in 1812 while the northeast trade wind was blowing. Neither in that island nor in its immediate neighborhood are any volcanoes. But a day or two before Morne Garou, in St. Vincent, 125 miles away to the west, had broken out into violent eruption. Its dust must have been hurled up into the region of the counter-trades, carried by them away to the northeast beyond Barbadoes, till it settled down into the contrary air current, and was then blown back on to that island. A similar instance once occurred at Jamaica, whither the dust from Coseguina, in Central America, 800 miles away to the southwest, came seemingly in the teeth of this lower current of air. Round each pole there is a zone of low pressure, so that there is some tendency to draw the air which has descended northward or southward as the case may be. But north of the belt of comparative calms—named sometimes after the circles of Cancer and Capricorn—at the "back" of the trade winds, the direction of the air currents is shifting and uncertain. The annexed diagram (Fig. 15) will give a general idea (and nothing more is attempted) of the air circulation of the globe, the arrows indicating the directions of movement, and those between the circle and the ellipse (which represents, in an exaggerated form, the atmospheric boundary) representing the paths of the rising and falling air.

Land masses, as has been said, produce irregularities in the trade winds. Over mountainous districts the aërial current may be forced up like a stream of water as it flows over a bowlder which projects from its bed; should the summits attain a sufficient height it might even be diverted. But the land masses, by producing variations of temperature, give rise to yet more important changes in direction. The temperature of the ocean as a general rule is fairly uniform over considerable districts; its variations also are slow, for water both acquires and parts with heat much less quickly

than the materials of which the earth's crust is usually composed. So the air which rests upon the surface of the ocean continues much more nearly at the same temperature by day and by night, and on successive days, than that which is above the land. This difference produces the great periodic winds, which in some parts of

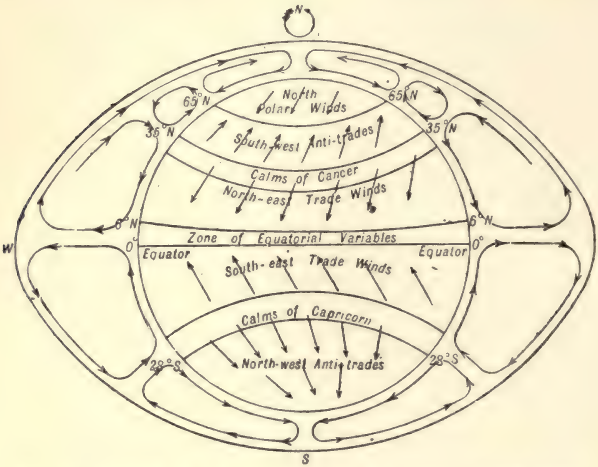


FIG. 15.—DIAGRAM OF AIR CURRENTS AND ATMOSPHERIC CIRCULATION.

the globe are called monsoons.* Those of Hindustan, with which English-speaking folk are most familiar, are due to the heating of the air above the plains of India and the plateaus of Central Asia. As the sun approaches the northern tropic the temperature of these regions, which are frequently arid, is greatly raised, and the air above them becomes much heated, and rises. Thus, precisely as already described, a draught is created which first neutralizes, then overpowers, the current of the trade wind. So long as the disturbing influence remains, so long does the monsoon blow. As a general rule, its direction is opposite to that of the trade wind, but the precise quarter from which it sets depends upon local circumstances—such as the trend of the coast, the configuration of the land surface, and the like. As the sun retreats southward the mon-

* From an Arabic word meaning "change."

soon ceases, and in the winter season the trade wind blows as usual. But the former is generally a much shallower current than the latter; probably its influence never extends for more than 4000 or 5000 feet above the earth. This is indicated by several facts; for instance, in Java the "smoke" from the crater of a volcano, which rises to a height of about 9000 feet above the sea, always drifts steadily toward the west under the influence of the trade wind. But for six months of the year the clouds on the lower slopes of the mountain are driven by the monsoon in an opposite direction. Winds similar to the monsoons occur on the west coast of Africa, especially in the Gulf of Guinea,* in the Gulf of Mexico, and over considerable parts of both coasts of South America. The Etesian winds of the Mediterranean—northern breezes set up in summer time by the heated lowlands of Egypt and of the Sahara—are also monsoons on a minor scale.

Land and sea breezes, as they are called, arise from similar causes, and might be termed daily monsoons. They occur in the warmer regions of the globe, on coasts where the temperature over the land is much higher by day than it is by night, while over the sea it remains fairly uniform. As the sun becomes powerful, the air above the land is heated by radiation, a draught, as already described, is created, and a breeze sets in from the sea.† This falls gradually at the approach of night. For a time the air is still, but at a later hour, when the land has been chilled by radiation, and the air above it has become colder than that over the sea, a current is created in the opposite direction, and the land breeze springs up, dying away as the day is dawning.

Local disturbances are produced by mountains, for each peak is like an island in the surrounding shell of atmosphere. It absorbs and radiates heat at a different rate, and acts in regard to the air as the land does to the sea. During the day the rocks are heated and a draught is created toward them. During the night they become very cold, so that the surrounding air is chilled and flows downward.‡ The mistral, the abomination of visitors to the

* The disturbance affects a very large area in Northern Africa, extending as far as the Sahara. (*See* Réclus, "The Ocean," ch. vi.)

† The sea breeze begins about 10 A.M., is strongest about 3 P.M., and is replaced by a land breeze about 8 P.M.—Ferrel, "Popular Treatise on the Winds," p. 221.

‡ According to General Strachey, these winds are very marked in the Himalayas, where they blow up the valleys from about 9 A.M. to 9 P.M.—Ferrel, "Popular Treatise on the Winds," p. 22.

pleasant regions of the Riviera, is a similar but still more marked instance. This is a bitter northwesterly wind, which descends in winter and early spring from the cold summits of the Cevennes and of the Maritime Alps, on to the lowlands of Provence and the coast of the Mediterranean. But France and the adjoining parts of Italy do not suffer alone; the Adriatic has its Bora, the Grecian Archipelago its Tramontana Negra or "Black Norther," for these winds are due not only to the neighboring mountain districts, but also to the fact that at this season the barometric pressure is usually high over a belt extending from the Spanish peninsula across Europe to the interior of Asia.

Lastly, the winds inconstant in direction and sometimes violent in character must be noticed. The ordinary winds and their changes result from inequalities of barometric pressure, which, as already mentioned, depend mainly upon differences of temperature at different parts of the earth's surface, and on the variable amount of aqueous vapor present in the atmosphere. The air over a district colder than the surrounding region contracts. If, then, the atmosphere be regarded as divided up into a series of zones or shells of uniform density, a slight indentation must be produced in each one of these above the colder area. Into this the surrounding air would flow, like water into a saucer the edge of which was depressed just below its surface, so that a larger quantity of air ultimately would be resting over this colder region. Thus the atmospheric pressure must be increased, and the barometer must rise. But when once this inequality of pressure was established, the air would naturally tend to flow away from the region of the high barometer toward the region of the low barometer till equilibrium had been restored.

In like way the heating of any portion of the earth's surface raises the temperature of the air above it, and produces a contrary effect, the barometer falls, and then an inflow is set up. But here also, as in the case of the trade winds, the rotation of the earth modifies the motion of the air. In the northern hemisphere that which is flowing southward to the center of a region where the barometer is low, moves also in a westerly direction, while that coming from the south is deflected eastward. Thus a rotatory motion is impressed upon the great body of air surrounding the depression, and a "cyclone" is the consequence. It rotates obviously in a direction opposite to that of the hands of a watch. But the contrary effect is produced in the case of an outflow from a

region of high pressure, so that an anti-cyclone, as this wind system is called, rotates with the hands of a watch. This rule, however, only holds for the northern hemisphere; in the southern, obviously, the reverse process must occur, so that its cyclones rotate in the same direction as the northern anti-cyclones, and *vice versa*. The rate at which the air moves depends largely upon the nature of the change in the level of the barometer; a steep gradient* in the readings will be associated with a rapid current of air or strong winds, a low gradient with gentle breezes. Steep gradients are commoner around areas of low than of high pressure, so that the former more frequently give rise to storms. The relations of the direction of the wind and the height of the barometer in the northern hemisphere are stated in the so-called law, named after Buys Ballot, by whom it was first enunciated. It runs thus: "Stand with your back to the wind, and the barometer will be lower on your left hand than on your right."† In the southern hemisphere, as a moment's consideration will show, "right" and "left" must be reversed.

The annexed copy (Fig. 16) of one of the daily charts issued by the Meteorological Office presents, in a form more readily intelligible than words, the relation between the height of the barometer and the direction of the wind. The curved lines show the "isobars," or lines of equal pressure, the lowest not exceeding 28.6, the highest recorded being 30 inches. The arrows indicate the direction toward which the wind is blowing. Over Wales lies a low pressure area, roughly circular in form, the center of which probably is not far from Dolgelly. The isobars over the greater part of the British Isles form closed curves, fairly symmetrical in outline. The arrows show that the air over the same area is circling round the center spot in the reverse direction to that of the hands of a watch. Over the southern parts of England westerly winds prevail; along the eastern coasts they are blowing from the south; in the northeastern districts they come from the southeast, and in the northern counties they have changed into east winds. Finally, over Ireland and the intervening Channel they become successively northeast, north, and northwest. If we follow the isobars over Europe toward the south, southeast, and east, we see that, so far as the chart goes, the same rule holds generally, though some slight abnormality may be noticed in the direction of the wind over the southeastern part of

* So called, because if the readings were plotted on a curve, this would slope steeply.

† R. H. Scott, "Weather Charts and Storm Warnings," p. 22.

France, which may be due either to the proximity of the Alps or to some disturbing cause outside the limit of the chart, but of which the widening of the isobars near the southeast corner may possibly give a hint. Toward the northeast of the chart the isobars open out, influenced, no doubt, by a high pressure area lying over

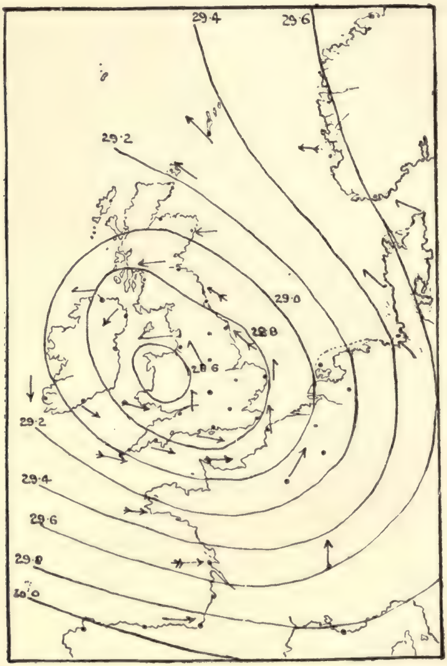


Fig. 16.—Chart of a Cyclonic Disturbance over the British Isles.

Scandinavia and part of Northern Europe; but as it affects only a small portion of the region covered by the chart, and the gradients here obviously are not so steep, it does not seem to produce any marked effect upon the winds.

Sometimes, more especially in the case of an anti-cyclone, the center of the system may remain practi ally motionless for several hours, or even for some days, but more commonly it moves over the earth's surface. If the area of approximately uniform tempera-

ture and the corresponding circulatory system be large, the winds will be steady in direction, and for some time will seem to follow a rectilinear course; the smaller the area and the steeper the gradient the more readily the cyclonic motion will be detected. In the British Isles, as everyone knows, the easterly winds in the winter and spring are dry, cold, and often steady in direction for many days. The reason of this becomes plain when a set of charts is studied on which the isotherms for this part of the year have been laid down. It is then seen at once that Northern Russia is a very cold region. The January temperature of a large part of Russia, with the Northeast of Scandinavia and the head of the Baltic, is below 14° F.; at Archangel it is 5° F.; while at the Land's End and in Kerry it is 41°. Between the temperature of the western frontier of Russia and the east coast of England there is a difference of about 15°; while in July, for the same latitude, the temperature in Russia is slightly higher than in England. In the one case there is a great fall of temperature in going eastward, in the other a slight rise; so that all through the winter and spring both Northeastern Europe, and a still larger area of Asia, have a temperature much below that of these islands. Hence if no disturbing causes interfere a draught of cold air must be set up by this vast refrigerator, which strikes on the eastern shores of Britain with its keenness hardly blunted by the narrow interval of sea. But strong gales and rainstorms more commonly come from the west, being generally the result of cyclonic disturbances approaching from that quarter; and their centers, for reasons presently to be considered, commonly pass to the north of these islands. Such a disturbance, therefore, will begin with a gale from the southwest,* which will "veer"† by the west, and pass away by the northwest. As the air has been traveling over the Atlantic, it is both warm and laden with moisture. If, however, a depression passes to the south of these islands, the wind begins from the southeast and "backs" through the east to the northeast. Such winds, as will be presently seen, are usually‡ less violent than those belonging to the other system.

When the gradients are extremely steep, and the velocity both of

* Sometimes the first symptom of the approach of a cyclonic disturbance is a wind from an easterly quarter, due, apparently, to a sort of "insuck" of the air.

† The wind "veers" when it changes with the sun—viz., in this order: east, south, west, north; it "backs" when the change is in a contrary direction—viz., from the east by the north.

‡ But not always, *e.g.*, January 18, 1881.

rotation and translation is very rapid, the result is a cyclone (in the popular sense of the term), typhoon, or hurricane. In the British Islands these visitations are comparatively unknown; their full terrors are displayed in tropical regions. But a tiny tornado can be seen on almost any hot summer day, when little columns of dust, only a few inches in diameter and a yard or so in height, run spinning along the highway. Sometimes, however, they get bigger, and, like growing children, try their hands at a little mischief: they whisk some haycocks into the air, and distribute them over the next field; they snap off or uproot a tree; they unroof a shed, or even blow down a wall. One Sunday morning, some years since, such a storm was seen traveling along the level fields three or four miles away from Cambridge—a moving "pillar of cloud," dark with whirling dust and leaves and boughs, not many yards in diameter. On its course it met with a clump of poplars. Some of the trees it snapped off short; others it split in two or three places, as a twig can be split by twisting it round; and it considerably interfered with the order of a Sunday school by entering in through the door at one end of the building and departing at the other by blowing out part of the wall, fortunately without injury to anyone. On the Continent these tornadoes are sometimes more formidable. The path of one which passed over the Italian Tyrol on July 18, 1880, could be traced for many miles, though at intervals nothing was harmed. This indicated that the whirlwind, as it were, "jumped" from place to place, the center of cone-like disturbance rising and falling, as may be seen in the eddies caused by an obstacle to the current of a rapid river. In the town of Botzen, for example, little harm was done. Clouds of dust were raised up higher than the cathedral spire, shutters were banged, windows occasionally were smashed, tiles came clattering down from the roofs; and if Tyrolese chimneys had been fitted with pots of the English pattern, probably many of them would have strewn the streets with sherds. In the pine woods, however, the whirlwind had often done not a little mischief. It had uprooted the tall firs, sometimes only for a space of a rood or two, but sometimes it had cleared a broad path even for hundreds of yards through the forest. Often the trunks of the fallen trees were flung one upon the other like a heap of gigantic spilikins.* Then, suddenly, the clearing came to an end, so that for a considerable distance, not a tree was injured.

* The firs in this region have shorter branches and proportionately taller boles than those of the other parts of the Alps.

Still larger and more formidable whirlwinds occur in North America. "In its path over the surface, the circling movement of the writhing air and the sucking action of the partial vacuum in the center portion of the shaft combine to bring about an extreme devastation. On the outside of the whirl the air, which rushes in a circling path toward the vortex, overturns all movable objects, and in the center these objects, if they are not too heavy, are sucked up as by a great air pump. Thus the roofs of houses, bodies of men and animals, may be lifted to great elevations, until they are tossed by the tumultuous movements beyond the limits of the ascending current and fall back upon the earth. When the center of the whirlwind passes over a building, the sudden decrease in the pressure of the outer air often causes the atmosphere which is contained within the walls suddenly to press against the sides of the structure, so that these sides are quickly driven outward, as by a charge of gunpowder."* Houses are wrecked, trees uprooted, trains blown over, bridges destroyed, roads blocked with *débris*. In ten years between one and two thousand persons were injured or killed in the Western States of America. Details of the effects of several tornadoes are quoted by Professor Ferrel.

The following extract,† describing a tornado at St. Cloud and Sauk Rapids, Minn., on April 14, 1886, gives an idea of their general character:

"The tornado struck the Mississippi River at a point opposite to the village of Sauk Rapids, and fishermen who were in full view of the crossing aver that for a few moments the bed of the river was swept dry; and in corroboration of this remarkable statement they showed me a marshy spot where no water had been before this event took place. Two spans were torn away from the substantial wagon bridge below the rapids, one span being hurled up stream and the other down it by the rotatory motion of the blast, great blocks of granite being also torn bodily out from the piers. The large flour mill near the bridge was leveled. The depot of the Northern Pacific Railroad was demolished, and the central portion of the village itself was attacked with the greatest violence. Being the county seat, the court house was located here, a substantial structure, of which only the vault, six iron safes, and the calaboose were left—the latter turned upside down. A fine new schoolhouse, costing $15,000, was

* Shaler, "Aspects of the Earth," p. 239.

† "Popular Treatise on the Winds," p. 385.

completely swept away. The Episcopal Church was so utterly ruined that the sole relic thus far found is a battered communion plate. The floor of the skating rink is all that is left of that structure. Stores, hotels, a brewery, and four-fifths of the residences in the village were scattered as rubbish along the hillsides or borne away for miles through the air."

About thirty-nine persons were killed and one hundred injured

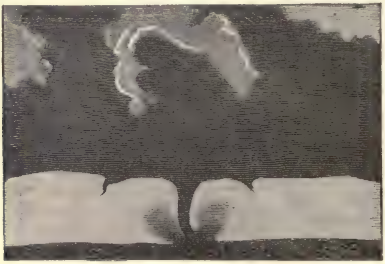


FIG. 17.—A TORNADO, FROM A PHOTOGRAPH.

The cloud around the base of the actual tornado indicates the dust and general disturbance produced by its passage.

on this occasion. In other accounts we read of a large gate being carried to a distance of 200 feet; a heavy lumber wagon "lifted up bodily and carried to the S.E. over a cornfield to a distance of 100 feet, without injury." A heavy "sulky cultivator," weighing about 600 pounds, was carried free from the ground a distance of 86 yards to the S.S.E., and broken by the fall. A ten-gallon keg was hurled about 40 rods, and a large iron-bound trunk, fitted with an extra heavy lock, was shattered to pieces and the lock found half a mile to the N.E. sticking into a rail; feather beds were torn to strips and their contents scattered broadcast, and articles of clothing were carried for four or five miles.

A hurricane in the West Indies, a typhoon in the Chinese or Indian seas, a cyclone or cyclonic storm, are all examples of atmospheric disturbances of a similar kind, on a larger, though not quite so violent, scale. As a general rule, the paroxysmal character of the disturbance is diminished as the area affected broadens; the height of the mass of air affected does not increase in proportion; the sucking motion at the center disappears, and is replaced by comparative calm. In these hurricanes two features obviously call

for an explanation: one is the rotation—at any rate, in the case of storms affecting small areas—the other the motion of translation. Each presents difficulties; for each more than one explanation has been advanced. One thing is fairly certain—namely, that the influence of even the larger hurricanes does not extend to a very great distance vertically from the surface of the earth,* a remark which is true of most aërial disturbances of a local character. Glimpses of clouds, floating in comparative calm high above the earth's surface, may be sometimes caught through the whirling rack of hurricane. Hence it seems more probable, although some have maintained a contrary opinion, that hurricanes, as a rule, originate in the lower regions of the atmosphere. Even if this view be adopted, a further diversity of opinion is found to exist. One party maintains that every cyclone, large or small, is generated by the action of two air currents, opposite in direction, their lines of motion forming tangents to the initial curve of rotation. The other party holds cyclones to be due primarily to differences of atmospheric temperature, and to be produced as follows: In an arid region, such as are some parts of the United States, the surface of the earth is greatly heated by the summer sun; by radiation from it the air immediately above is warmed, and so becomes lighter than the colder layers higher up. Usually the one will rise, the other will descend; but it may occasionally happen, if no further disturbing conditions exist, that a heavier layer may be floating for a time upon one that is lighter. Such a state of thoroughly unstable equilibrium will be ended by the slightest disturbance, and the result will be catastrophic. Some writers have suggested that even the tall trunk of a dead tree on one of those wide inland plains may suffice to produce an upcast draught and to puncture, as it were, the upper fluid, and thus cause a downward rush through the breach. The air in descending acquires a rotatory movement, like water in flowing through the escape pipe at the bottom of a bath, and the unstable condition of the atmosphere is favorable to a rapid extension of the disturbance. Such storms, to which the term tornado is often restricted, seldom affect an area more than about 500 feet in breadth and some 30 miles in length. The cyclones proper may have a width of from 200 to 500 miles, though the velocity of the wind varies greatly at different parts of the area

* The vertical height of an Indian hurricane seldom much exceeds 10,000 feet, and often is not much more than 5000 feet, above sea level.

disturbed, while the length of their course may also be proportionately greater.

The eye or center of the storm is a comparatively calm spot, about which the wind first increases, then decreases in velocity. This, however, is by no means uniform at equal distances from the center, for another factor has to be taken into consideration. The eye of the storm does not remain at rest, but moves rapidly, its velocity sometimes exceeding a hundred miles an hour. Suppose

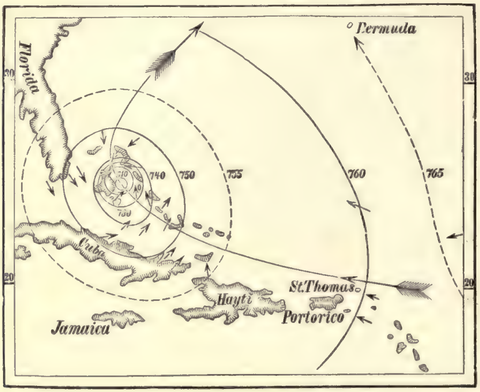


FIG. 18.—THE COURSE OF A TORNADO IN THE WEST INDIES, 1868.

The figures show the air pressure in millimeters (765 = 30.118 in.; 710 = 27.953 in.). The smaller arrows show the direction of the wind around the center of the storm.

the storm be traveling from west to east, and rotating in the opposite direction to the hands of a watch, the velocity of the wind in the southern half of the cyclone will be greater than in the northern, for at the one extreme the velocity of translation will be added to that of rotation, but at the other will be subtracted from it. This may make all the difference between a destructive tempest and a moderate breeze.

Such cyclones seem to be on too great a scale to be originated by a cause comparatively local, like two layers of air in unstable equilibrium. That they usually happen at the season when the regular winds are reversed is also a significant fact. Thus of 365 West Indian hurricanes on record between the years 1493 and 1885, 245 occurred in the month of October, when the sun has passed south of the line, and the increasing heat of the South American

coast produces a flow of air from the northern continent transverse to the ordinary course of the northeast trade wind. In the Indian Ocean also cyclones are most numerous after either the vernal equinox or the great heat of summer. Thus the examination of a list of the hurricanes in the southern hemisphere has shown that not one of them occurred in July and August, and more than three-fifths raged during the first three months of the year.

In the northern hemisphere a cylone generated near the West Indies first travels toward the N.W., then it turns back to follow the general direction of the coast line of the United States, and, lastly, blows itself out in a N.E. or N.N.E. direction. In the southern hemisphere the disturbance originates in the Indian Ocean, not far from the equator, to the south of Ceylon, and moves in a S.W. direction toward the islands of Réunion, Mauritius, and Madagascar, whence it turns away to the S.E., and expires before it reaches the Antarctic seas. In each case the curvature of the path is probably due to the same cause—the earlier part being the result of the resistance of the trade wind; the later, after the storm has escaped from this influence, to its "overrunning the latitudes," as happens with the counter-trades.

In close connection with the atmospheric circulation is the fall of rain. Both are due to the same primary cause—solar heat. If a little water be spilt on the pavement when the sun is shining, the flags are soon dry again—the fluid has been converted into vapor and has been absorbed by the atmosphere. Air at a given temperature can retain a certain quantity of water vapor. It is then said to be saturated. If its temperature be lowered it is no longer capable of holding the same amount, so the vapor is condensed, at first in tiny droplets, floating in the air, forming clouds; afterward, when these increase in quantity and augment in size, the water descends as rain. So if vapor-laden air rise into colder regions of the atmosphere, the result is clouds and perhaps rain. If, however, the temperature of the air be raised, a cloud, already formed, will disappear—it passes back into vapor and becomes invisible. Thus the morning mists often vanish before the sun. The amount of water which a mass of air can contain in the form of vapor depends upon the temperature, but does not vary with it directly. So if two saturated air currents at different temperatures mingle, the mixture is no longer able to contain the whole of the water as vapor, and some of it is condensed, and this may form a cloud or may be precipitated as rain.

Fog, mist, and cloud do not essentially differ, and are only distinguished by their position. When vapor is condensed immediately above the surface of a plain or of the sea, it is called a fog. This sometimes forms a very thin layer. It may cover the meadows, yet the trees may stand up clear above it as they do from the water in a flood. A vessel might be passing through a bank so dense as to render invisible a rock only a few yards ahead, and yet the sun might be shining on its topsails. Sea fogs are commonly produced by the mixture of a warm vapor-laden current with a colder one. Thus the Atlantic to the south of Newfoundland, and off the coast of the United States, is sometimes not free from fogs for days together, owing to the warm air from off the Gulf Stream mingling with that chilled by the Arctic current. Mist only differs from fog in being less local, and perhaps more elevated in position; and cloud is only a mist regarded from the outside. In a mountain region the advance of a cloud over the slopes may be often watched. Occasionally its boundary is almost as sharply defined as that of a jet of steam—it comes rolling on, as if it were alive, blotting out crag and pasture as it advances, till it envelops the observer in a white mist.

Perhaps no better illustration can be found of the development of a cloud than is supplied by the "streamers" which sometimes are attached to mountain peaks. From the crags a long cloud banner floats to leeward, like a pennon from a mast. It is generated thus: The current of air which strikes the peak contains a considerable amount of vapor, though it is not yet saturated. It is chilled by contact with the rocks, its saturation point is at once lowered, and the vapor is condensed into a cloud; but the part of the current thus affected bears but a small proportion to the whole mass of air, so that, as the two flow on, the temperature of the colder streak is gradually raised, the cloud is vaporized, and finally disappears.

The forms assumed by clouds depend upon a variety of causes, such as the nature of the air currents, the action of wind, and that of electricity. The steam from a locomotive engine often affords excellent illustration of the different varieties. For a short distance from the top of the funnel the air is transparent; then the vapor condenses into the heavy mass called a *cumulus;* this if the wind be blowing hard is riven into *cirrus*. But if the engine be standing under a shed, the cumulus floats upward till it forms a *stratus* beneath the roof, and this locally, by the fall of the condensing vapor in drops, may become a *nimbus*.

All water, whether in puddle, pool, lake, brook, or river, is subject to loss by evaporation; but the ocean, of course, is the great source of supply for the rainfall of the globe, and the sun is the great pumping-engine by which its waterworks are kept in action. The earth is made fertile by the heat of the sun and the cold of space; without these it would not be even habitable. Were it not for the former the water would never be raised, and the shores of the arid lands would be laved in mockery by the useless ocean; were it not for the latter the vapor would pass away by diffusion into space till at last there would be no more sea, for the water would never fall back upon the earth as rain, and thus the land would be no less desolate.

Nature's process of "rain making" is fully illustrated by the usual course of a day in a tropical island during the rainy or summer season. The sky at sunrise is clear; presently clouds form, and by ten o'clock the heavens are densely covered. Shortly afterward rain begins to fall, and before noon there is a downpour. About five o'clock the weather improves, the clouds break, after which the sky clears and the night is fine. The explanation of this periodic change is not difficult to find. As soon as the sun had risen to some distance above the horizon the ocean began to give off abundant vapor, which was carried up by the rising current of air until it reached colder regions; here condensation set in, followed by precipitation. But as the sun declined toward the west and the day became cooler evaporation gradually ceased, the supply of vapor was cut off, and by degrees the sky became clear.

The amount of rain precipitated and its distribution throughout the year depends to some extent upon causes more or less local in character, but the following laws are found usually to hold:

(1) The amount of rainfall on the globe decreases from the equator toward the poles.

(2) If the surface of a continent remains nearly at the same level, the rainfall is heaviest on the coast, and decreases inland.

(3) In passing from plains up the slopes of mountains the rainfall usually increases; but if the chain rise to a sufficient height, precipitation reaches a maximum, after which it diminishes.

(4) In the temperate zones of the globe a greater amount of rain falls on the western coasts of large masses of land than on the eastern; but in the tropics the rule is reversed.

(5) Certain regions have their rainy seasons; others are almost, or even quite, rainless.

The reasons for the first four rules may be briefly summarized. The heaviest precipitation takes place near to the region of greatest evaporation—much of the water is spilled near the pump. As changes of temperature are more marked over land than over the ocean, a coast is likely to be a zone of precipitation; but beyond this the conditions above a level district will continue to be fairly uniform, and further precipitation will not occur till the vapor impinges upon a colder surface or is forced up into colder regions of the atmosphere—in other words, till the land becomes distinctly higher; so as the mountains rise precipitation increases, till most of the moisture has been removed from the air. In the more temperate regions of the earth the rainfall is heavier on the western coasts because winds are frequent from the west and southwest in connection with the counter-trades. These, especially if they blow from the latter direction, are comparatively warm and moist; while those from the east and northeast, which impinge upon eastern coasts, come from colder regions, and thus are comparatively dry. Besides this, they are traveling toward a warmer climate, and so are able to retain whatever moisture they may have already absorbed. But in regions nearer to the equator the contrary rule holds. Here the trade winds dominate, which, as they blow from the eastern half of the compass, have traveled over a large expanse of ocean, and thus have become charged with vapor.

Excellent illustrations of the former rule are afforded by the British coasts. The rainfall in the eastern counties ranges from about 22 to 25 inches per annum, but on the western coast from 35 to 40 inches, or even more. The effect of hills is distinctly indicated, even in the comparatively undulating region of the southeast of England, for the annual rainfall rises from 26.13 at Greenwich to 30.77 on Salisbury Plain.* But this variation becomes yet more marked in the northwest district. At Liverpool the rainfall is about 35 inches; at Manchester it is 38.18 inches; but at the waterworks of the former town, near Rivington Pike, it is 54.7; and at those of the latter, near Woodhead, it is 52.3. So that the Lancashire portion of the Pennine range, which reaches a height of rather more than a thousand feet above the western lowland, makes a difference in the rainfall of from 14 to 18 inches. Further north, where the mountains of the Lake District rise nearer to the coast, and yet more abruptly, the difference is still more

* At Chittenden (from information communicated by R. H. Scott, Esq., F. R. S.).

strongly marked. On the Cumberland coast the rainfall is about 35 inches, but at the head of Borrowdale and on the surrounding hills it is commonly not less than 150 inches, and during wet years is even more. For instance, in 1872, 131.3 inches was measured at Wasdale Head, 186.25 inches at Seathwaite in Borrowdale, and as much as 243.9 inches on the Stye Head Pass, between the two places. Ben Nevis also affords a good illustration of the effect of a western coast and a comparatively high mountain. Fort William at its base, though by the seashore, is at the head of a long inlet which is bordered by high hills. The rainfall accordingly is heavy,* being 77.33 inches; but at the observatory on the summit of Ben Nevis, 4406 feet above the sea, the corresponding amount is 129.47 inches. The same effect is produced by mountainous districts in the interior of continents—for instance, in the wide valley of the Rhine, between the Black Forest and the Vosges, the rainfall is only 22 or 23 inches; but on the higher parts of the latter range it varies from 43 to 47 inches. Again, at Geneva it is about 32 inches; at the St. Bernard Hospice it amounts to 79 inches.

But the classic instance—for it is the most remarkable on record—is afforded by the Khasia Ghauts, a range of hills rising above the great alluvial plains of the Ganges, in front of the Bhootan Himalayas, to a height of from 4000 to 5000 feet above the sea, and separated from that chain by the valley of the Brahmapootra. South of the delta lie the steaming waters of the Indian Ocean, from which the saturated air at the period of the monsoon travels northward toward the mountains. On the delta itself the rainfall is considerable, amounting to about 80 inches. But here the aërial current merely scatters its superfluous moisture. When it strikes upon the Ghauts, the height of which probably almost equals the depth of the current, the precipitation begins in earnest, and the rain literally streams from the clouds. At Chirapoongi a fall of 30 inches in twenty-four hours has been recorded;† the annual fall commonly exceeds 500 inches, sometimes is even more than 600 inches, and most of this is precipitated during six

* This is heavy in another sense, for the total weight of water thus precipitated on an acre of ground is approximately 7730 tons. Could all of it be collected, the water that comes down on each square mile would supply a city containing rather more than 100,000 people, at an allowance of thirty gallons per head per day. The amount annually required by 1333 persons is equivalent to an inch of water on a square mile.

† By Dr. (now Sir W.) Hooker. In England an inch in the same time is thought a rather unusually heavy rain, and four times that amount is not often reached, and very rarely exceeded.

months of the year. The Ghauts plunder, but they are not sufficiently lofty to exhaust, the aërial current; it overflows their summits and crosses the Brahmapootra valley. But for a time it discharges no more rain—it is like a sponge which a child has squeezed as tightly as he can; a man's grip is needed before it will yield more moisture. So the lower slopes of the Bhootan Himalayas, to a height of some 5000 feet above the sea, are arid. But this chain towers up far above the highest summits of the Ghauts; so the aërial current breaks upon that mighty rampart, which exacts the "utmost farthing" of moisture as the price of passage; hence its higher slopes enjoy a fairly abundant rainfall, and are clothed with a luxurious vegetation.

The above instance has afforded an example—though on a small scale—of a rainless district; but there are extensive regions, some of which are nearly, others entirely, without rain. But little falls over a large area south and east of the Caspian Sea; in the inland country of South Africa or Southern Australia; in the Arctic regions of America and Asia; in those south of latitude 60° in the opposite hemisphere; in the cañon country of Colorado and some adjoining parts of the United States, and in a comparatively small district of Western Mexico. The last receives little more than an occasional shower, but there are other regions which are doomed to total abstinence. These are three in number, two of them appearing to be rather nearly connected. The first, and smallest, is in the southern hemisphere, on the western slopes of the Andes, a long and narrow strip extending for about 30° southward from latitude 5° S., through Peru and part of Chili. The second is a much more extensive region, and in quite another part of the globe. It is a belt of land about 10° in breadth, which begins not very far from the west coast of North Africa, and extends over the Sahara and through the Libyan Desert to the other side of the continent, crossing the Red Sea into Asia. It has now become narrower, and so continues across the North of Arabia into Persia, where it terminates near the western border of Afghanistan, having covered about 60° of longitude. The third region is rather narrower and less extensive, for it begins about longitude 75° E. and terminates in longitude 115°, including part of Eastern Turkestan with the Desert of Shamo or Gobi. The first of these regions lies in the zone of the southern trade winds. Thus, though the Pacific is near to it on the west, the ocean cannot relieve the thirsty land, for the air currents set off the shore. To the east rises the lofty chain of

the Andes, and beyond this is the whole continent of South America, so that all supplies from that quarter are effectually intercepted. Somewhat similar causes, though rather more complicated, account for the aridity of the second region. Little rain can come from the west, for the air currents tend to flow southward and westward, and that little is arrested on the coasts. For the reason just given, the southern quarter would not in any case avail much, and in that direction lies, at first, part of the continent of Africa, afterward almost the whole of Arabia. The Mediterranean is not a sheet of water sufficiently extensive to furnish a large supply of moisture, and as the air from that quarter is moving southward, over comparatively low ground, there is nothing to cause precipitation. The desert of Gobi is guarded on two sides and on part of a third by lofty mountain chains. These effectually desiccate the air which may cross them. For the remainder of the northern side the ground continues fairly high; from this quarter also but little moisture could ever come, while from the eastern seas the winds will not often blow, and will be dried before they have passed the Chingan Mountains.

Thus the whole system of the atmospheric circulation and of the rain supply is extremely complicated. Dependent primarily on the heat of the sun and on the cold of space, it is largely affected by secondary causes, such as the distribution of land and water, and the configuration of the terrestrial surface. Local changes may have far-reaching effects, and the climate of any region may be greatly altered by important modifications in the outlines of the continents—that is to say, in the physical geography of the globe. The present is not a stereotyped repetition of the past, though it supplies the materials for inference and induction. The land which now is well watered once may have been arid; and the desert of to-day, where the sparse bent grass withers and the dust storm whirls over the dry plains, may have been "a place of broad rivers and streams," where the lowlands were green with lush herbage, and the slopes clothed with impenetrable forests.

CHAPTER IV.

THE WATER REGION.

FULL seven-tenths of the earth's surface, as has been already stated, are covered by water. Every river may be said to have its source in the ocean and its grave in a sea. Without an ocean there would be no vapor, without vapor no rain, without rain no streams. By these the water is transferred from slope to slope, from hill to valley; here it may wander deviously over the plain; there it may stagnate for a time as a marsh or broaden out into a lake; but, except in some few cases where its contents are slowly diminished by evaporation and its stream is dried up among arid sands, every river empties itself at last into some great water basin. This occasionally is an inland sea—such as Lake Baikal or the Caspian Sea—but is more commonly the ocean.

In river water some mineral salts are present. Of these parts may be removed by various agencies during its journey, but other constituents remain, and are concentrated in the basin in which the river comes to an end. Thus while the water of a lake through which a river runs is fresh—*i. e.*, contains an imperceptibly small proportion of certain mineral salts—that of an inland sea and of the ocean is always more or less saline, as can be recognized by the taste and by other rough tests.

	English Channel.	*Mediter. ranean.*	*Black Sea.*	*Caspian Sea (Baku).*	*Great Salt Lake (Utah).*	*Dead Sea.*
Chloride of sodium ..	2.7059	2.9424	1.4019	8.5267	11.8628	3.6372
" potassium ..	.0765	.0505	.0189	(trace)	.0862	.8379
" magnesium ..	.3666	.3219	.1304	.3039	1.4908	15.9774
" lime ..	——	——	——	——	——	4.7197
Sulphate of magnesia ..	.2295	.2477	.1470	3.2493	——	——
" lime ..	.1406	.1357	.0104	1 0742	.0858	.0889
" soda ..	——	——	——	——	.9321	——
" potash ..	——	——	——	——	.5363	——
Carbonate of lime ..	.0033	.0114	.0364	.0554	——	——
" magnesia ..	——	——	.0208	——	——	——
Bromide of magnesium ..	.0029	.0556	.0005	——	——	.8157
Water	**96.4747**	**96.2348**	**98.2337**	**86.7905**	**85.0060**	**73.9232**
	100	100	100	100	100	100

The foregoing table* exhibits the amount of soluble salts present in ocean water. For purposes of comparison analyses of the water of some inland seas have been added.

Slight variations are noted in the total amount of the salts present in ocean water at different times of the year and in different parts of the world. According to Dittmar the samples collected during the voyage of the *Challenger* afforded quantities which varied from 3.301 per cent. of the water for the southern part of the Indian Ocean to 3.737 for the North Atlantic, about latitude 25°.

The following table gives the proportion of the saline constituents contained in an average sample of oceanic water:

Chloride of sodium	77.758
" magnesium	10.878
Sulphate of magnesia	4.737
" lime	3.600
" potash	2.465
Bromide of magnesium	0.217
Carbonate of lime	0.345
	100

But in addition to these, many other elements are present in sea water, though generally in extremely minute proportions. The gases dissolved have been estimated as ranging in amount from just below two to just above three per cent. These are oxygen, nitrogen, and free carbonic acid, the last being only occasionally present, and always in very small quantities. The proportion of oxygen is greatest in the surface water and least in that at the bottom. Besides these, iodine, fluorine, phosphorus, silicon, barium, may be mentioned among others, and a considerable number of the metals, including such ordinary substances as iron, copper, lead, manganese, silver, and gold, and such rarities as cæsium and rubidium. In fact, the ocean water contains, though always in comparatively small and often in extremely minute quantities, most of the elements which enter into the composition of the earth's crust, and it is probable that nearly all may be actually present, though in such inconsiderable amounts as to elude the investigator.

Between the contours of the land and those of the adjacent ocean bed, as a general rule, a certain relation may be observed.

*Compiled from Prestwich, "Geology," pt i. ch. vii., and Geikie, "Textbook of Geology," book iii. part ii. sect. ii. § 4.

Both alike either shelve gently or descend rapidly downward; but in each case the submarine slope is less steep than the subaërial one. Still, occasionally, abrupt changes of level have been noticed in the sea bed, as, for example, off the Abrolhos, when on one side of Captain Fitzroy's vessel the lead descended to a depth of 4 to 6 fathoms, but on the other side the soundings were from 16 to 22 fathoms. As this locality is not within a region of coral reefs, so marked a difference can only be explained by assuming the existence of a submarine cliff. Again, the ocean floor is found in some cases to descend from the margin of a continent or a large island gradually and steadily to great depths, while in others this downward slope does not really begin till a considerable interval of comparatively shallow water has been traversed. Thus the bed of the North Atlantic descends with fair uniformity from the coast of the Iberian peninsula and the nearest parts of France to a depth of 1000 fathoms, which is found about forty miles away, and for a considerable distance off the northwest of that region it reaches 2000 fathoms at about double this interval; but the British Islands, with the northern parts of France, rise from a submarine plateau, all of which lies within the contour line of 100 fathoms. A vessel does not pass over the margin of this plateau until it has proceeded about five-and-thirty miles west of Valentia, and more than two hundred miles west of the Land's End. Then the sea bed begins to fall much more rapidly, and slopes down at an angle of about eight degrees to a depth of full 2000 fathoms. The bed of the Atlantic between Europe and America consists of two broad troughs, which follow roughly the coasts of the respective continents, and commonly vary in depth from about 2000 to 2800 fathoms. These are separated by a submarine plateau, also of considerable breadth, which supports the Azores, and seldom rises more than some 1800 feet above the 2000-fathom contour line, except in the immediate neighborhood of these islands. This plateau at its northern end is united to another one which runs transversely from the British Isles to Greenland. The course of this submerged causeway is indicated by the Shetland Isles, the Faroës, and Iceland, a large part of it is well within the 500-fathom contour line, and its greatest depth does not exceed about 600 fathoms.

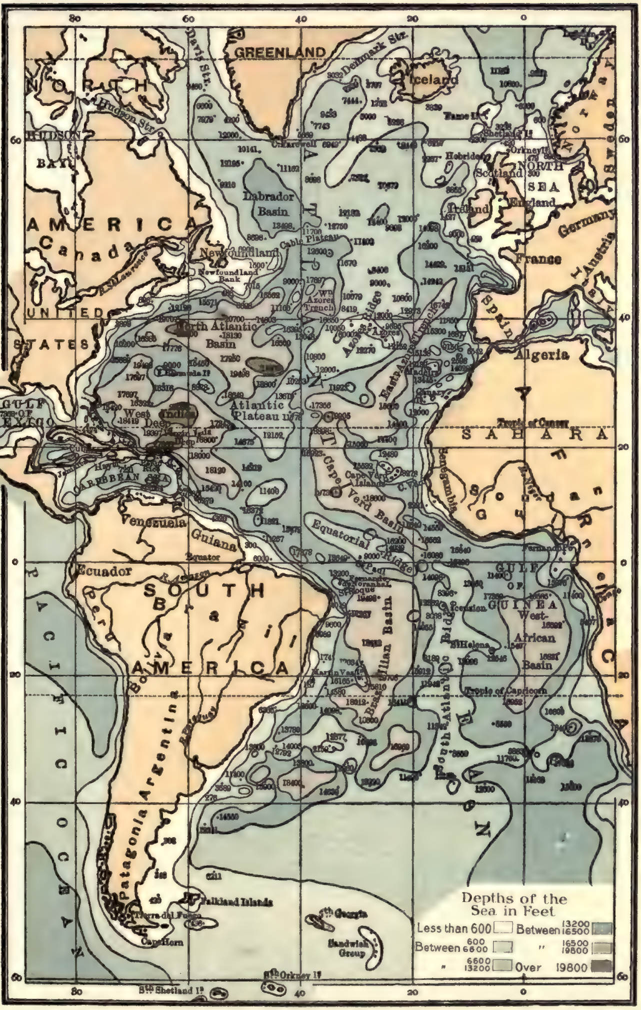
The two basins mentioned above deepen gradually to the south; the intervening plateau also sinks, though it continues to form a distinctive feature in the general contour of the ocean floor.

FIG. 19.—MAP OF NORTHWESTERN EUROPE, WITH THE SUBMARINE CONTOURS.

(Plate I.) At last, between latitudes 10° and 23° N., a part of the eastern basin, somewhat triangular in form, with one side following the general contour of the African coast, attains a depth of over 3000 fathoms. The western basin also shelves down to a depression which, however, is even larger and deeper. This in shape roughly resembles the letter C, and it extends from about latitude 35° N. to 14° N., the back, as it were, following the general contour of the American coast, and resting on the West Indian Isles. In their neighborhood, at no great distance from the island of St. Thomas, soundings of 3875 fathoms have been obtained, the greatest depth known in the North Atlantic. The intervening submarine plateau, already mentioned, is prolonged to and across the equator, but it throws off one spur which runs westward, at a general depth of from 1500 to 2000 fathoms, to the coast of South America, north of the mouth of the Amazon, and another which runs eastward to the African coast. Its general course beneath the water is marked by the islands of St. Paul, Ascension, and St. Helena—volcanic masses which, like beacons on a reef, indicate the presence of this great inequality in the ocean floor. Then the bed of the Atlantic Ocean, as a whole, rises toward the south, mounting up to the icy land which encircles the southern pole. Thus the Antarctic continent is surrounded for a considerable distance by a sea which deepens very gradually for the first thousand fathoms.

The submarine contours of the Pacific Ocean (Plate II.) are more difficult to describe. It is deeper on the whole than the Atlantic, though its surface is far more broken by islands, which, however, do not very materially reduce the average soundings, but rise up rather abruptly from great depths. The basins also are less closely related in their distribution to the coasts of the greater continents. A comparatively shallow plateau unites the Japanese Islands to Asia, and that continent to America. A rise of less than 50 fathoms would replace Behring's Straits by dry land, and convert the Arctic Ocean into a *mare clausum*. Southward from this submerged causeway the sea bed plunges down to great depths. Skirting the islands of the N.E. Asian and N.W. American coasts lies the so-called Tuscarora Deep—a vast area below the 3000-fathom contour line. In this, near the Kurile Islands, north of Japan, a depth of 4655 fathoms was measured. To the south of this deep is a considerable area over which the soundings are from 2000 to 3000 fathoms, and this rises gradually to a long plateau, which comes

THE ATLANTIC OCEAN.



within the 2000-fathom line, extending for nearly 10° west of the Sandwich Islands. South of this area, beneath the equator, a considerable tract is between 2000 and 3000 fathoms deep, but it is interrupted by sundry small groups of islands, which, however, produce comparatively little effect upon the general level of the bed. A very broad plateau, seldom more than 100 fathoms below the surface, but interrupted here and there by comparatively small yet rather deep basins, links Asia with the Philippine and other adjacent islands, and these with the Australasian Islands and Australia. The plateau continues, though sinking to a distinctly greater depth—for it can now be more easily traced by the 2000-fathom line—through the Solomon and Fiji Islands. Near the latter it divides, one branch taking a westerly course by the New Hebrides toward the southern part of Queensland, and thus inclosing the basin of the Coral Sea; another running diagonally to New Zealand, and thence, in a northwesterly direction, toward the arm already mentioned. To this it is joined rather to the west of New Caledonia, thus inclosing another basin. New Zealand is parted from New South Wales by a broad channel over 2000 fathoms deep, but it throws out submarine spurs toward the latter and the Antarctic plateau, which is reached without obtaining any soundings of that depth. The eastern half of the Pacific presents more uniform contours, it is almost everywhere considerably below the 2000-fathom contour line, and not seldom approaches 3000 fathoms, but from the coast of Chili a long spur-like plateau passes beneath Juan Fernandez, and may be traced as far as Tahiti, much of it being less than 1500 fathoms beneath the surface. An isolated basin, 4475 fathoms, was found by the *Challenger* south of the Ladrone Islands; a sounding of 4530 fathoms was obtained north of the Friendly Islands, and one of 4428 fathoms south of them; but the most curiously situated hole in the Pacific forms a narrow trench, nearly 4200 fathoms deep, off the coast of Chili, north of Coquimbo.

The Indian Ocean exhibits greater simplicity in the contours of its bed. It has an average depth of about 2500 fathoms, reaching 3000 in the deepest part between Java and Northwestern Australia, and at last it rises gradually southward toward the Antarctic plateau so as to come within soundings of about 1000 fathoms in the neighborhood of latitude 40°. From this plateau rise Kerguelen, Crozet, and Prince Edward's islands. A considerable space in the Mozambique Channel, which separates Madagascar from

Africa, is rather deeper than 1500 fathoms, and the Seychelles are somewhat more closely related to that island than to the continent. The Mascarene Islands, however, appear to be fairly distinct from both, since the plateau from which they rise is surrounded by water over 1500 fathoms, though it is most in connection with that of the Seychelles.

The description given above indicates that the land masses of the globe are generally most nearly linked together by their northern ends. If the level of the ocean were lowered by 100 fathoms only, as already stated, it might be possible to pass dryshod from Australia to Asia, and then to travel by the latter to North America, and so to the end of the New World's continental land. A complete circuit of the globe could not be made roughly along the line of the Arctic Circle, for open water would still remain between Northwestern Europe and Greenland, but the depth of this generally would be comparatively slight, nowhere amounting to 1000 fathoms, while the Antarctic plateau is everywhere separated from the continental masses by a channel of at least this depth.

The Mediterranean Sea is not only a basin in itself, but it also consists of a group of basins. If the general level of the ocean were lowered by 200 fathoms, the Straits of Gibraltar would be closed and Europe united to Africa by an isthmus. One-half that amount of lowering would unite Majorca with Minorca, Sardinia with Corsica, Malta with Sicily; and by closing the Straits of Otranto would greatly augment the area of Italy. By such a change almost the whole of the Adriatic would become dry land; the Po and the Adige, the rivers of the Istrian and Dalmatian coast, and of the Eastern Apennines, would all flow into a shallow inland sea north of the Straits of Otranto. The Mediterranean then would be almost cut in two, but a rise of rather more than another hundred fathoms would be required to make a second land passage from Africa to Europe, for soundings of 240 fathoms are obtained in a narrow channel south of Malta. The submarine area inclosed between this region and the Straits of Gibraltar really consists of two basins, which are separated by a plateau starting from the Genoese coast and prolonged through Corsica and Sardinia southward to Africa. The western basin is 1600 fathoms deep; the eastern, which is rudely triangular in form and smaller in area, attains a depth of 2300 fathoms. A large part of the Ægean Sea is within the 100-fathom contour line, and its depth nowhere exceeds 500 fathoms, except in a well-marked basin which lies off

THE PACIFIC OCEAN.

Depths of the Sea in Feet

Between 0-6600 · Between 6600-13200 · Between 13200-16500 · Between 16500-19800 · Over 19800

the northern shore of Crete, and corresponds generally in outline with that island. A rise of 100 fathoms would put an end to the Eastern Question by closing both the Dardanelles and the Bosphorus, and so converting the Black Sea into another Caspian. It also is a well-marked basin, the greatest depth of which is 1070 fathoms; and even the Sea of Marmora takes the same peculiar form, its deepest soundings amounting to 358 fathoms.

Attention may be called, before proceeding further, to an irregularity in the ocean floor which, though on a smaller scale than those already described, is rather more sharply accentuated. A close relation, as has been said, generally exists between the slope of this and of the neighboring land. Cases, however, may be found which might appear, at first sight, exceptions to the rule. For instance, off the coast of the Landes in France the continuity of the shallow sea bed is broken, near Cape Breton, by a channel, the bottom of which lies some 50 fathoms below the submarine plain on either side. Again, though the Baltic is a shallow sea, all parts of it being less than a hundred fathoms deep, and this measurement not even being approached till some distance south of the island of Gothland, a deep channel exists in the Cattegat, which passes along the Norwegian coast till it is lost in the Arctic Ocean. The bed of this channel lies at a depth of about 400 fathoms.* So if the bed of the North Sea, with the adjacent coast, were elevated 600 feet (Fig. 19), and replaced by a great plain watered by the rivers of Britain and of North Central Europe, Norway would be still separated from it by a deep salt water inlet bounded by the northwest coasts of Zealand and Southern Sweden. A still more marked instance of these irregularities is to be found at the "Swatch of no ground," as it has been called by mariners, in the Bay of Bengal. Here the delta of the Ganges is fringed with low islands and swampy banks overgrown with mangroves. For fifteen miles seaward the soundings generally do not exceed 16 fathoms. Beyond the contour line of a hundred feet the sea bed descends gradually, though more steeply. But from the deeper part of the Indian Ocean a long narrow inlet extends toward the mouth of the Ganges. At its lower end, where a marked indentation in the submarine contour line is first perceptible, soundings of 900 fathoms are obtained; these decrease rather rapidly to 600 fathoms, and from this to 450 fathoms. The channel has now become very

* The deepest soundings are in the Skager Rack, and amount to 437 fathoms.

strongly defined, and is continued, shallowing with extreme slowness, until it rises up more rapidly to the level of the ordinary channel of the Ganges. But even at the above-named distance from the coast the bed of the Swatch lies 1700 feet below the muddy plateau on either side. Similar interruptions, comparatively abrupt, are known to occur in other parts of the world, and will be again referred to in a later part of this volume. It will be seen, then, that they are generally indicative of submerged river valleys.

If, however, these cases, apparently exceptional, be put aside, the following conclusions result from a study of the contours of the beds of seas and oceans: (1) That, as already said, these contours correspond generally with those of the neighboring land, but that in them the horizontal scale stands in a different relation to the vertical. If a model were constructed to exhibit the contours of the land surface and of the ocean bed, and if a cast were taken of this in some flexible material, which was then turned so as to make another globe, it would be found that on the former model a series of ridges, comparatively narrow and steep, formed an interrupted network, in the wide interstices of which the surface shelved down into basins of variable depth; while on the other a series of gently undulating plateaus was parted by narrow furrows, the beds of which were broken by somewhat deeper pits, corresponding, of course, with the mountain peaks of our globe. (2) That the floor of the ocean does not descend gradually from all quarters to one lowest point, but that it consists of a number of basin-shaped depressions. If its waters were to be gradually dissipated by a process of evaporation, so that island were united to island and continent to continent, the single continuous ocean would be broken up into two or three huge inland seas, which, as the water disappeared, would be further subdivided into insulated basins. These, however, would not always occur at the greatest distance from the present coasts, and it would be frequently observed that in the case of some of the smaller basins land elevation and ocean depression stood one to another in a curious relation, something like that of a cast and its mold. To this reference must be made in a future chapter; at present it will suffice to emphasize the fact that the earth's surface, speaking figuratively, is dimpled by the ocean basins and is wrinkled by the mountain chains.

The great mass of water which covers so large a part of the globe is in constant motion; it is ruffled by the winds; it is swayed by

the tides; it is traversed by currents; perhaps only in its most profound abysses is it actually at rest. Of these disturbances the waves, which are the direct result of the winds, are most conspicuous to man. By these also important changes are brought about in the contours of the land, a subject which will receive attention in a future chapter. But just as the influence of the waves is rarely felt beyond a very moderate distance above the level of high tide, so does it seldom extend to any great depth below low-water mark, very commonly not even so far as twenty fathoms.

The winds also produce considerable effects locally on the actual

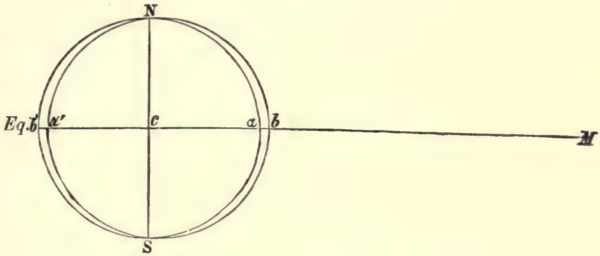


FIG. 20.—THE ATTRACTION OF THE MOON IN PRODUCING TIDES.
M. Direction of Moon; *a'b*, *ab'*, Shell of Water.

level of the sea. Many years since it was observed by Smeaton that a steady breeze, when blowing along a canal four miles in length, caused the water at one end to be four inches higher than at the other; but the effects on larger masses are on a far greater scale. In the estuary of the River Plate the level of the water may be lowered, when a southwesterly gale is blowing, by from twelve to eighteen feet in less than half a day; and large tracts of land are laid bare, which, when the wind drops, are again overflowed.

The tides also—in other words, the joint influence of the sun and moon—are potent factors in disturbing the ocean waters. Other planets produce similar effects, but these are too small to be practically appreciable. If the earth were covered with water, had no moon, and presented always the same face to the sun, the fluid would take the shape of an egg,* one end pointing toward the sun and another directly away from it. In the one case the sun tends to draw the water away from the earth, and in the other the earth

* Strictly speaking, a prolate spheroid.

away from the water, so that the same result is produced on either side.* If the earth be supposed to rotate, as it actually does, about an axis, then the water would constantly tend to assume this ovoid form, so that its surface would be traversed by two broad waves, the crests of which would be 180 degrees apart. The moon, if it acted alone, would produce a similar effect, so when both are acting the result at one time represents the sum, at another the difference of these effects. The mass of the sun vastly exceeds that of the moon, but as the latter is so much nearer than the former to the earth, it produces the greater effect—the tide wave due to the moon being about five feet in height, and that due to the sun only about two feet. If, then, the straight line joining the centers of the sun and moon pass through the middle of the earth, their effects are combined, whether they be on the same side or on opposite sides of it, and the result is a "spring tide," corresponding with new or full moon. But when the lines joining the center of the earth with that of the sun and with that of the moon are at right angles, then the solar low water, as it might be called, corresponds with the lunar high water, and the actual tide with the difference between them, or the result is a "neap tide."

As, however, the ocean is interrupted by continents and land masses, the phenomena of the tides are of a much more complicated character than in the ideal case which has been described. Strictly speaking, a tidal wave is generated in every sheet of water, but the disturbing influence acts for too short a time on even the largest lake to produce any perceptible effect. Even in the Mediterranean the difference between high and low water is but slight—in the more open parts not more than from one to two feet. The tidal waves take their origin in the greater ocean basins, and roll onward toward the coasts. As the depth of the water diminishes the pace of the wave decreases, but its effect becomes more marked; with a shallowing sea bed and a narrowing channel the advancing wave, as it were, becomes piled up, and the difference between high and low water increases. For instance, on the coasts of South Wales and Devonshire it amounts to about 27 feet at the mouth of the Bristol Channel, and it gradually increases as the shores converge,

* If the mass of the sun be represented by M, the distance of its center from that of the earth by R, and the radius of the latter by r, then the difference between the attraction of the sun on the earth as a whole, and its attraction on a particle placed on the surface of the latter, in the line joining the centers, is represented approximately by $\frac{2Mr}{R^3}$.

till at last it is as much as 42 feet in the estuary of the Avon and about 50 feet in that of the Wye.*

Occasionally, however, a tidal chart exhibits results which seem to be anomalous. Near the mouth of the Wash the difference between high and low water is 20 feet; thence it diminishes eastward along the Norfolk coast, though the bed of the North Sea is becoming both shallower and narrower, until at Lowestoft, in Suffolk, it amounts only to 6 feet. The anomaly, however, is apparent, not real. The tidal wave is generated, not in British seas, but in the open Atlantic. As it approaches these islands, it is parted by them as is a stream by the pier of a bridge: one branch passes up the English Channel, and even makes its way through the Straits of Dover, the other flows into the North Sea, round the shores of Scotland. Each of these branches affects the water between the East Anglian and the Dutch coasts, but paths of different length have been necessarily traversed in order to reach this region, and so the waves arrive in a different phase of movement. Opposite to Lowestoft this differs by six hours, or, in other words, when it is high tide for the one wave it is low tide for the other. They do not, however, neutralize one another, because one wave has been diminished in power by its passage through the Straits of Dover; still it is sufficiently potent to reduce the difference between high and low water by at least four yards.†

The tides, however, like the large rivers which flow into the sea, only produce movements of transference in its waters comparatively near to the coast. Other movements exist, the effects of which, though at first sight inconspicuous, are in reality, as will be subsequently explained, of the utmost importance. These may be distinguished as the ocean currents and the oceanic circulation. The former may be compared to the draughts which are so often an annoyance in a room, the latter to the slow movement of the air when the ventilation is good. As in this case, so also in the ocean, the former attract the greater attention. This, however, is not surprising, since the currents directly affect the surface of the ocean.

* Seventy-two feet is given as a rare, but possible, difference between high and low water. See Lyell, "Principles of Geology," ch. xx.

† In some cases, as in the channel formed by a large island, the tide, after falling for a little time, again flows back. Thus at Southampton the water, after ebbing for about half an hour, again returns before its final retreat. The reflux is produced by the portion of the tidal wave which has made its way into the eastern part of the Solent, after flowing from the westward, round the south side of the Isle of Wight.

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FIG. 21.—DIAGRAM REPRESENTING CURRENTS IN THE OCEAN.

They are restricted to the upper layer of its waters, and their influence probably seldom extends to a depth of more than a very few hundred feet. Like all other currents, they follow paths fairly well defined, and have been termed, not inaptly, the rivers of the ocean. But the oceanic circulation disturbs enormous masses of water—its effects in some cases extend down to the greatest depths; probably only the most profound abysses of the insulated basins escape from its influence and contain water which is absolutely stagnant. But this circulation has to be inferred rather than detected by direct observation. It is revealed, not by the ordinary experimental tests, but by a comparative study of the records of deep-sea temperature. This indicates that the deeper ocean waters cannot be in equilibrium, but those of high and low latitudes must be in constant process of exchange.

Currents exist in all seas, and traverse each of the greater ocean basins. In the latter case they may be traced for some hundreds of miles; they transfer water from equatorial to polar, and from polar to equatorial regions, forming, as it were, a hot and cold water system on the surface of the globe, and so becoming factors of much importance, as will be seen presently, in determining the climate of particular localities. The map (Fig. 21) indicates their general distribution and relation; it may be sufficient to restrict any detailed description to the one which bears the name of the Gulf Stream, since it is the best known and is of most importance to the inhabitants of these islands. This, as is commonly said, has its origin in the Gulf of Mexico—that may be regarded as the boiler in which a great mass of water is raised to a temperature some degrees higher than the average of neighboring seas. But a boiler, if its outflow pipe were left running, would soon be emptied, if not provided with a feeder. So the Gulf of Mexico is supplied from the Caribbean Sea, and that receives a current which sweeps along the South American coast northward from Cape S. Roque, and so on. But to return to the Gulf Stream. It passes into the Atlantic, as through a gigantic floodgate, between the peninsula of Florida on the one side and the island of Cuba and the Bahamas on the other—a mighty stream, about 37 miles in breadth, the depth of which is estimated at about 200 fathoms, and the velocity at about 3½ miles an hour on the average, though it sometimes attains to nearly 5 miles. Various statements have been made as to the quantity of water discharged by this huge ocean river. On a moderate estimate it is two thousand times that of the Mississippi,

but by some authors it is considered to be very much more. Broadening as it flows,* the Gulf Stream, toward latitude 40° N., gradually divides itself into two branches. Of these the eastern one sweeps round by the Azores, and is deflected first in a southern, then almost in a western direction, until it is lost at last in the still waters of the Sargasso Sea. The other branch maintains a north-easterly course, gradually broadening out and becoming less easily recognized as it approaches the western shores of Europe. Geographers are at issue as to how far in this direction it can be traced *as the Gulf Stream.* Some hold that it cannot be identified after it has reached approximately the latitude of Lisbon, while others maintain without hesitation that it washes the western coasts of Britain, and even of Norway, and produces effects, direct or indirect, so far north as Spitzbergen.

A current in any direction, unless the water thus transferred be removed in some other way, must imply a return current in the opposite one, and the exceptions to this rule are not likely to be numerous. So a current parallel with the Gulf Stream flows southward from the Arctic regions (Fig. 22). Currents of water, if flowing in the direction of lines of longitude, of course are deflected by the rotation of the earth in the same way as winds, and they obey the same law. Thus the Gulf Stream keeps edging away toward the east, and the return current, which is formed by a combination of the "Arctic current" down the east shores of Greenland with the one flowing between that country and Labrador, skirts the American coast until it disappears beneath the waters of the Gulf Stream.

The Gulf Stream and other ocean currents are conspicuous phenomena. Their existence is indicated by the transport of floating bodies, as when the West Indian bean is washed up even on the shores of Iceland,† or by the marked difference in the temperature and by other characteristics of the surface water. That of the Gulf Stream, for instance, has a blue tint, that of the returning American current a greenish one, and the two masses are sometimes divided almost as sharply as the Rhone and the Arve at their confluence below Geneva. But the existence of the oceanic circulation is far less easily detected. This was only established when the tempera-

* Between the Bermudas and New York (early in May, 1873) the Gulf Stream was estimated as about 60 miles wide and 100 fathoms deep, running at the rate of three knots an hour.—"Voyage of the *Challenger*" (The Atlantic, ch. v.).

† *Entada gigalobium*, from the Antilles, has been found even on the coast of Spitzbergen.—Réclus, "The Ocean," ch. viii.

ture of the ocean down to great depths had been ascertained by a series of observations which were rendered practicable by improved methods of sounding. One instance of this circulation—that which has been discovered in the Atlantic—may be sufficient. On either

FIG. 22.—DIRECTION OF CURRENTS TO AND FROM THE ARCTIC OCEAN.

side of the equator, for full 35° of latitude, the bed of the ocean, excepting comparatively near the shore and in one or two deeper basins, varies in depth, roughly, from about 1500 to 2500 fathoms, and it shallows slightly, but still definitely, in a southerly direction. In the northern part of this area the bottom temperature is about 36° F., but it falls, of course, toward the polar edge of the basin. But after a time the temperature decreases still more perceptibly in a southward direction; about latitude 20° N. it reaches 34° F., and under the equator is even as low as 32.4° F., or only slightly above the freezing point of fresh water. If submarine isotherms are plotted down on a section of the Atlantic from latitude 40° N. to 40° S., the line of 35° F., as it comes from the latter side, is seen to

slope downward in the North Atlantic till it strikes the bottom about latitude 20° N., and then disappears for a considerable time. Similar bends are shown by the other lines of equal temperature in the deeper parts of the ocean. It is therefore clear that as the icy sea which surrounds the southern circumpolar land is so much greater in volume than the Arctic Ocean, with its limited area, narrow straits, and ramifying channels, the zone of highest bottom temperature in the Atlantic lies, not, as it might be expected, immediately under the equator, but much nearer to the Tropic of Cancer; or, in other words, that the Antarctic water, creeping down along the ocean floor, overshoots the equator.

The principal cause of ocean currents is at present a matter of dispute. The oceanic circulation, it can hardly be doubted, is mainly due to differences of temperature; and by some authorities the ocean currents are attributed to the same cause. That the equilibrium of their waters is disturbed by heat in more than one way can hardly be doubted. Under the equator the mean annual surface temperature is often as high as 80° F.; in latitude 55° on either side it may fall below 40° F. By this a circulation is certainly caused; a current also may be produced in some cases, especially if the shelving coast of a continent tends to "bank up" the colder water. Again, the level of the sea in equatorial regions is lowered by evaporation, a mass of water being annually removed from the whole surface which can hardly be less than twelve feet in thickness. Much of this, no doubt, is returned either almost immediately as rain or before long by the rivers draining tropical lands; still this loss must considerably lower the ocean surface, and equilibrium must be restored by an influx from regions where the evaporation is comparatively slight. That the sun is a pumping engine of mighty force can be proved by a single instance. The area of the Dead Sea is about 330 square miles; from it, as is well known, no river issues, so that the inflowing water must either be absorbed by the earth, which is not likely to happen to any great extent, or be removed by evaporation. The Jordan, just before entering the Dead Sea, is 80 yards wide and 7 feet deep, and flows at the rate of 3 knots an hour. Hence the volume of water discharged by the river into the sea should suffice in the course of a year to form a layer over the whole area not less than 10 feet thick. But as no permanent rise takes place in the level of the waters, this quantity at least (for no notice has been taken of the rainfall or of smaller tributary streams) must be pumped up by the sun from the

surface of the Dead Sea. But the same process must affect seas and the ocean generally in the warmer regions of the globe. For instance, hardly any water is contributed to the Red Sea by rain or by rivers, while the amount which is removed by evaporation cannot be less than eight feet annually from the whole surface, and may well be rather more. The loss, then, must be supplied by an inflow from the Indian Ocean through the Strait of Bab-el-Mandeb, and this current is known to exist.

Moreover, changes of temperature affect the specific gravity of water. This operates in a direct and in an indirect way. Water expands when heated and contracts when cooled, so that a cubic foot of it obtained at the equator weighs less than the same quantity taken up at the Arctic Circle. What must happen when the two are in communication can be demonstrated by a very simple experiment.* Take a small glass tank, such as a common aquarium, and fill it with water. On the top of a piece of black rock, a few cubic inches in volume, sprinkle some cochineal, and put this close to one end of the tank, introducing it into the water so carefully and gently as not to disturb the coloring matter. Then fix a good convex lens in such a position that the rays of the sun are brought to a focus upon the piece of rock; at the same time place on the water, at the opposite end, a lump of ice, and upon this pour a small quantity of milk. As the rock is heated the surrounding water, which is becoming stained by the cochineal, is warmed; it expands, and a red cloud mounts upward. But at the other end of the tank the water, which is rendered slightly turbid by the milk, is chilled by contact with the floating ice, and so a whitish cloud sinks downward. Presently the former begins to drift along the surface toward the ice, the latter along the bottom toward the heated rock, and thus a system of oceanic circulation is established. But it is difficult to understand—even if every allowance be made for the effects of continental barriers and irregularities in the ocean bed—how these slow, creeping movements of vast masses of water can be converted into the more limited and superficial, but more active, phenomena of currents. In Nature a cause may be a true one, yet not the principal cause. Rivers by their influx, the tides as they ebb and flow, solar evaporation and changes of temperature, may, and in some cases certainly do, pro-

* It was devised and described by the late Mr. J. F. Campbell in "Frost and Fire," vol. i p. 68, a book as entertaining as it is suggestive.

duce effects; still all these seem inadequate to explain such a current as the Gulf Stream. So another solution has been sought, and many, perhaps the majority, of those who have studied the question regard the ocean currents as produced by the wind. But with this general statement complete agreement ceases. For instance, in the case of the Gulf Stream, some attribute it to the action of the trade winds, which either force the water into the Gulf of Mexico, where it is piled up, so as to flow by gravitation through the other outlet, or impel it forward, as the water on the surface of a pond is driven before a puff of wind. But neither of these explanations seems satisfactory. Each, like those previously considered, may be a partial statement of the truth, but both appear inadequate to produce effects so strongly marked. So a more comprehensive explanation has been proposed. In this it is maintained that the currents, whether in the ocean or in the air, cannot be regarded as isolated phenomena. They form systems, the several parts of which are more or less connected and linked together. Thus the ocean currents, as a whole, are produced by the aërial currents, also acting as a whole.* This supposition is confirmed by a comparison of charts representing the paths of each. The modifications introduced by the intervention of land masses are doubtless more important in the case of the ocean currents; at the same time a relation exists between these and the more permanent atmospheric currents sufficient to render it highly probable that the one stands to the other in the position of effect and cause.

We have said that rain and rivers feed the ocean. But it is at once their grave and their birthplace; for without the ocean there would be no rain, and without rain there would be no rivers. It is needless to add that without the sun's heat there would be neither rain nor rivers nor ocean; for there would be no atmospheric circulation, no evaporation, nothing to precipitate, for water would only exist as a solid rock, since the temperature of the earth would be that of outer space.† The cause and distribution of rain have been already sketched in the chapter dealing with the atmosphere, to which it seems more naturally to belong. The effect of rain, whether acting directly or when collected in rivers, belongs to a later part of the subject, but the history of water in the form of snow and ice requires a brief notice before this region is finally quitted.

* Croll, "Climate and Time," ch. xiii.

† Estimated as $-239°$ F., or $271°$ below the freezing-point of water.

Water, under atmospheric pressure, becomes a crystalline solid at a temperature of 32° F. In the fairy flowers built up during a hard frost from the vapor in a room upon the cold surface of the window glass, in the tiny stars, with each of their six rays like a frond of frozen fern, showered down from the clouds on a calm winter day, the crystals exhibit their true form.* But in ordinary ice they are massed more or less irregularly together; in ordinary

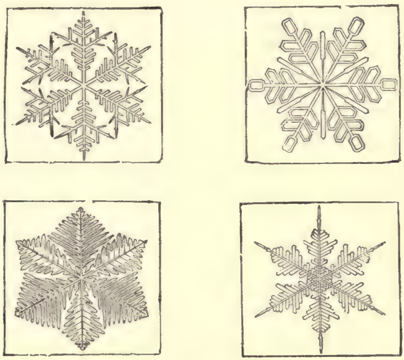


FIG. 23.—SNOW CRYSTALS.

snow they are broken by the breeze, and are gathered as they drift through the air into irregular flakes. The same process of accumulation—"the little making a mickle"—continues as the ground is covered by the falling flakes, and layer piled on layer forms beds of snow. These, when heaped up in sufficient masses and under favorable circumstances, are the sources of glaciers. In temperate regions where the land lies comparatively low the snowfall of winter disappears before the warm sun and winds of summer; but in more arctic lands, or where mountain ranges rise high enough above the sea to give a suitable climate, the contrary result is produced. The snow accumulates; the results are snowfields, glaciers, and ice-caps.

In a mountain region like the Alps the process of the formation of a glacier can be seen in its several stages. At a certain height above the sea the mean annual temperature sinks to 32° F. Permanent

* Ice belongs to the hexagonal system of mineralogists, and is modeled on a six-sided prism.

beds of snow are found shortly above this line; in the Alps they begin at about eight thousand feet; the exact position being dependent upon a number of circumstances, such as the nature of the rock, the configuration and aspect of the ground, and the like.* These beds, however, do not increase beyond a certain amount, for after that has been reached the warm weather expenditure exhausts the cold weather supply, accumulation in the earlier stages being the result of favorable circumstances dependent on the locality. As a rough illustration, they may be likened to a man who has succeeded in saving a small capital early in life, but afterward is obliged to live up to his income. They do not form true glaciers, but remain as snowbeds. One change, however, takes place which makes them differ from ordinary masses of fresh-fallen snow. As their upper surface is melted by the warmer air, much of the water so produced trickles down into the underlying mass. But on this journey through the frozen particles it is robbed of its own tiny store of heat, which, however, is insufficient to produce in them any material change, being of no more use than a hungry man's last crust of bread among a famished multitude; so the water goes back again into ice, and the snow by this process is gradually cemented together into a fairly solid mass. The weight also of the upper layers helps in solidifying the lower, for, as has been demonstrated by experiment, a heap of loose snow can be converted by the use of an hydraulic press into a cake of solid ice; † but this action becomes important only at a later stage, when the thickness of the accumulated mass is materially increased. Both causes operate in converting snow into ice; but at first the one, afterward the other, plays the more important part.

At an elevation of about a thousand feet higher on the slopes, supposing other conditions favorable, the snowbed, particularly if lodged in a depression, such as the head of a shallow valley, is found to be slightly prolonged in a downward direction, and its lower part presents a nearer resemblance to ordinary ice. This is the first stage in the formation of a glacier. At a somewhat higher level, particularly when the head of the valley is encircled by mountain peaks, a glacier is completely developed. The surrounding

* In addition to the above-named causes of variation, the snow line, which is about seven hundred feet higher than where the mean annual temperature is 32° F., lies lower, owing to the geographical position, by at least the same amount, in the northern part of the Alps than it does in the southern.

† Tyndall, "Heat as a Mode of Motion," ch. vi.

crags remain bare, though snow has lodged on their ledges and gathered in their gullies; but it has cast a thick mantle on every slope, and the icy covering streams down like a flowing robe into the recess in which the valley has its origin. Here also, just as already described, the snow has gathered, and is often augmented by avalanches from above, as the fresh-fallen layer slips off from the hard crust of the old snow. On the peaks, and in the combe beneath, the accumulated material is in the intermediate condition between snow and ice. The mass is sufficiently solid to rupture under considerable strain, yet it often retains indications of the process by which it has been formed, bed above bed being exposed in fissures, as in any cliff of stratified rocks. It is imperfectly transparent; is white in color, owing to the numerous tiny bubbles of imprisoned air; and the light which struggles through it and faintly illuminates the deeper chasms is green rather than blue. The mass which has thus accumulated moves down the shelving bed of the valley, creeping on like a stream of hardening mud or tar, or lava; and so a glacier is formed. The head of a mountain valley is almost always more or less bowl-shaped, and the sides a little lower down contract, so as to form a passage comparatively narrow. Through this the descending ice is forced by the pressure of the mass above. It suffers as the individuals of a crowd in a struggle to escape from a hall down a narrow passage. The molecules are squeezed close together; the interstitial air is extruded; the porous granulated mass—half snow, half ice*—is changed into solid ice. The stratified structure of the mass in the upper basin is completely lost, and a new structure, as a rule, appears. As to the cause of this, much controversy formerly existed; but it is now generally considered to be the result of pressure. This—the banded structure, as it is usually called—consists of alternating layers of white and of blue ice, the former being full of tiny air bubbles. These layers vary in thickness, ranging roughly from half an inch to an inch and a half. The structure is easily seen where chasms permit a view into the mass of the glacier. On the surface they are disclosed by their unequal weathering, the more porous bands yielding more readily to the disintegrating effects of the atmosphere. In a short time also the fine dust, blown by storms from the crags on either side of the valley, lodges in the furrows, and makes the structure yet more conspicuous, so that it can be seen from a con-

* Called *névé* in the French districts of the Alps, and *firn* in the German.

siderable distance. Not seldom it is faithfully recorded in the photographs of glaciers.

As the glacier descends into warmer regions it melts away. Some of the effects of this change will be more appropriately described in a later chapter; at present it may suffice to say that the water thus produced runs for a time in streamlets on the ice, is engulfed in fissures, carves out for itself subglacial channels, and ultimately emerges as a torrent at the end of the glacier. Here,

FIG. 24.—TERMINAL ICE-CAVE AND BIRTHPLACE OF A RIVER.

generally, a shallow cavern is formed in the ice—a blue grotto, often of singular beauty. Its charms, however, like those of a siren, are best contemplated from a respectful distance, for now and then large masses of ice come crashing down from the roof, breaking away without the slightest warning.* The lower limit of a glacier depends primarily upon temperature, secondarily upon a variety of local circumstances, a discussion of which would demand too much space. In the Alps the larger glaciers never descend much below four thousand feet above sea level, and seldom quite reach this limit. But the limit, and of course the volume, of the glaciers in any region is by no means constant. Taking the Alps as an example, changes not unimportant have occurred within the last three centuries, even within the memory of many now living. The facts at present on record are insufficient to determine accurately

*I was sketching one day the ice cave at the end of the Rhone glacier (of course, at a perfectly safe distance), when a mass of ice, more than enough to load a cart, dropped suddenly from the roof.

the period of increase and decrease—probably it is not capable of a simple expression—but apparently it is something like half a century. For nearly thirty years the tide of the Alpine ice has been slowly ebbing; it seems now to be turning again. We who knew the glaciers at the beginning of that period—about the year 1860—can remember how marked a change took place during the following decade. Of this it may suffice to quote a single instance. The Unter-Grindelwald glacier in 1858 descended to the bed of the valley between it and the village, and one could step without difficulty from the level part, above the last icefall, onto the rocks near the Bäregg Châlet. In 1870 slopes and crags of ice-worn rock—some 200 yards in vertical height—intervened between the bed of the valley and the ravine in which the glacier hid its diminished head; while from the neighborhood of the châlet one looked upon the ice down cliffs, which indicated that its thickness in this part had been diminished by some 60 or 70 feet.

The rate at which an ice stream moves varies in different parts of the same glacier and in different regions. It obeys always the same rule as a river, its motion being more rapid in the middle than at the sides, and in the upper than in the lower part. Its pace is quicker in the summer than in the winter. The greater Alpine glaciers in the course of a year move through about as many feet as there are days.* But the huge glaciers of Greenland appear to travel at a less deliberate pace. To them the latest published observations assign velocities which vary, according to circumstances, from about 20 to 40 feet a day, the great Jakobshaven glacier even attaining to 50 feet. As a rough average, they may be said to move about thirty-five times as fast as the glaciers of the Alps.†

The precise cause of the motion in a glacier has long been a subject of controversy among physicists. A full discussion of its details would extend this chapter to an inordinate length, so that a very brief summary must suffice. The various theories may be ranged in two groups, the one regarding gravitation, the other heat,

* The following are more precise statements (quoted by Prestwich, "Geology," part ii. ch. xxxiii.):

Glacier du Bois	(mean of 5 years)	364 feet	per annum.
Rhone Glacier	(" 7 ")	366 "	"
Aar Glacier	(" 14 ")	338 "	"

† See Prestwich, "Geology," part ii. ch. xxxiii., for numerous details and a discussion of the consequences to which these facts point.

as the ultimate motive cause. De Saussure, who was the first to make any scientific investigation of glaciers, contented himself with remarking that they slid down the rocky beds of valleys as a result of gravitation. It was, however, soon pointed out that this bare statement required amendment, for a glacier does not move with an accelerated velocity, like an avalanche or any other falling body. The late Mr. Hopkins showed experimentally that a mass of ice, if its base were slowly melting, could descend a slope of rock within certain limits of inclination* without increase of speed, while at higher angles it slipped down in the usual way. The late Professor J. D. Forbes maintained, as the result of his careful investigations of the glaciers of the Alps, that ice was really a plastic body, so that its movements resembled those of a mass of hardening tar. But by unfortunately applying the epithet "viscous" instead of "plastic" to the substance he gave rise to misconception, and aroused opposition. Professor Tyndall, who was the most active assailant of his hypothesis, brought forward experiments to show that, while ice demeaned itself as a plastic body under pressure, it failed so to do under tension. So he availed himself of the property of ice which had been observed by Faraday and termed regelation—namely, that two masses of it are frozen together if they are brought into contact when their surfaces are moist. In Professor Tyndall's opinion a glacier was being constantly ruptured by strain, and the broken pieces, as they slipped downward, were brought into contact and cemented with new surfaces; so the whole mass of ice, by repeated fracturing and freezing, as it were "shuffled" down the slope. Lastly, the late Professor J. Thomson called attention to the fact that the freezing point of water is lowered by pressure,† and suggested that the motion of a glacier might be explained in the following way: Certain parts of a mass of ice, resting as it does on a rocky slope, must be subjected to considerable pressure. These accordingly melt. This change affects the equilibrium of the mass; parts formerly at rest can now slide downward; the water moves to another position, is relieved from pressure, and again passes into a solid condition, so that the ultimate result is the same as in the preceding hypothesis.

* In an experiment with a slab of ordinary sandstone the angle was about 15°. Described by W. Mathews in the "Alpine Journal," vol. iv. p. 413.)

† Water, in passing into ice, increases in volume, and if prevented from obtaining additional room will remain fluid at temperatures below 32° F. Consequently a mass of ice, if compressed into a small space, returns to a fluid condition.

The claims of heat as a motive force have found fewer advocates. De Charpentier was the earliest. He asserted that a glacier, instead of being a completely solid mass, was traversed by a number of minute capillary tubes, in which water still remained in a fluid condition. This was affected by the heat of the sun, being expanded or contracted according to circumstances. By these movements the mass as a whole was affected, and their result was to impel it slowly downward. In this hypothesis several difficulties are obvious, but one only need be mentioned—namely, that after a most careful search not the slightest trace of these alleged capillary tubes could be detected. The late Canon Moseley also regarded heat as the motive cause, for he thought that he had discovered the following difficulty in any "gravitation" hypothesis: Different parts of a glacier admittedly travel at different rates. Suppose, then, that two masses of ice—say two cubic inches—which at any moment are in a horizontal line are frozen together. As a result of the differential movement one of them, at the end of a certain interval of time, is somewhat in advance of the other. Particles on the adjacent surfaces which were once in contact are so no longer. "Shearing," to use the technical term, has taken place, and to produce this result a force must be exerted. In order to ascertain the amount of this, Canon Moseley devised a machine, and his experiments demonstrated, as he thought, that the force required to shear ice must exceed any pressure which could result from gravitation. But the motive power of heat had been impressed on his mind by a practical experience. He was a canon of Bristol. The lead upon the roof of that cathedral had been recently renewed, and on the southern side had caused considerable trouble and expense by breaking loose from its fastenings and "crawling" downward. The reason for this perverse propensity became evident on consideration. When a slab of lead was heated by the sun it expanded on all sides, but in an upward direction it moved against gravitation and in a downward one with it; so that the enlargement in the latter direction was greater than in the former, and thus the mass as a whole moved slightly downward. But when the slab cooled and contracted, the upper part moved with gravitation and the lower against it, so that again a descent took place. Canon Moseley regarded a glacier as analogous to one of these sheets of lead—as heated and cooled in a similar way, and so moving along its bed by expansion and contraction, always in a downward direction. The explanation is ingenious, but it does not

escape some of the physical difficulties which are incurred by the last one; and the experiments, which seem to be fatal to the "gravitation" hypothesis, as will be presently pointed out are not really conclusive.

The hypothesis advanced by the late Dr. Croll ends the list. He looked upon glacier ice as consisting of molecules at a temperature very little below their melting point. The heat of the sun, in passing through the mass, must be transferred from molecule to molecule. Suppose, then, we consider the case of a line of them, A, B, C, D, etc., in the direction of movement; B receives from the mass above it, limited by A, a certain quantity of heat. This is sufficient to change it from a solid to a liquid condition. The mass above is thus deprived of its support, and slips forward as B is in the act of transferring the heat to C; but now, as C melts, B becomes solid, and another slip occurs; and so forth. Thus the whole mass moves by a series of molecular slips. The idea is ingenious, but not very intelligible, and it does not appear to find much favor with physicists.

As regards these rival hypotheses, one point is certain: that be the cause what it may, the motion of a glacier is analogous to that of a plastic solid. Streams of hardening pitch, of mud, or of lava present us with close analogies—not seldom with exact reproductions—of the phenomena exhibited by a glacier. It may also be observed that the experiments of Professor Tyndall to disprove the extensibility of ice, and those of Canon Moseley to ascertain its shearing force, are less conclusive than they appear to be at first sight, because no account was taken of the element of time. It is a matter of everyday experience that a substance may bend without breaking, or be changed in form by forces comparatively small in amount if only sufficient time be allowed. A stick of sealing wax snaps if an attempt be made to bend it suddenly, yet if it be fixed at one end with the other projecting from the wall of a room at ordinary temperature, it will assume a curved shape in the course of a very few days. Experiments have proved that ice, in process of time, does bend by its own weight without any sign of fracture,* and in other respects demeans itself as a plastic body. The difficulties probably are more apparent than real, and spring from our imperfect knowledge of the molecular condition of bodies. Solid and fluid are antithetic as conceptions of the mind, but not as

* W. Mathews, "Alpine Journal," vol. iv. p. 426.

actualities in Nature. For a certain set of conditions, it is correct to think and safe to reason of a substance as if it were in the one state or in the other; but it by no means follows that either these conditions or this method of reasoning are capable of indefinite extension. So, while it may not yet be possible to fix with precision the ultimate cause of the motion of a glacier, it seems safer to say that its demeanor is that of a plastic solid.

One result of glacier movement may be described before quitting this part of the subject—for incidentally it has been mentioned

FIG. 25.—CREVASSES IN A GLACIER.

already—namely, the formation of crevasses (Fig. 25). These are produced by strains greater than the ice can resist. For instance, the difference in the rate of movement of adjacent parts of a glacier is greater near to its sides than it is at the center. If the line A B (Fig. 26) represents a group of particles, and if in a certain time the particle at A has moved to C, and that at B to D, those which occupied the space A B should now extend from C to D; but without actual stretching this is impossible, so the strain is relieved by fracture. A crack accordingly opens somewhere between C and D

in the direction *e f*. Thus crevasses are frequent near the edge of a glacier, and they point in a general upward direction. But, further, the bed of the valley down which the ice sheet descends is not uniform in its slope; here and there it increases, perhaps rapidly, in steepness. Obviously the ice in passing over this part is strained, like a board when it is bent over the knee, so that fissures open across the glacier. Irregularities in the form and in the bed of the valley, the action of the weather, movements in the broken mass, add to the confusion, so that a great "icefall" is sometimes a scene of the utmost complication—a wilderness of yawning chasms, broken ridges, and tottering towers; like a cataract suddenly

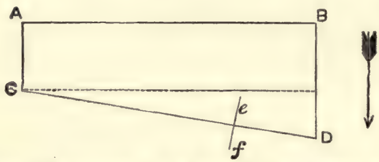


FIG. 26.—DIAGRAM SHOWING THE RATE OF MOVEMENT IN A GLACIER.

frozen, or, even more correctly, like an ice avalanche instantaneously arrested—until the bottom of the steep is reached, when the mass is slowly reunited, the chasms are gradually closed up, and the ice returns to a more normal condition, though for a considerable distance the "hummocky" surface of the glacier is a memorial of the past disturbance.

Snow and ice are direct agents of great importance in modifying the surface of the earth. That subject will be noticed in a later chapter; this one may be ended by calling attention to the important part which they play in the storage of water. The rain which falls upon a mountainous district runs quickly down into the valleys, and so is carried away. The neighboring lowlands—especially in a region where the rains are periodic—are liable to alternations of flood and drought; but if the summits rise sufficiently high to be covered with snow and to generate glaciers, these become reservoirs, from which a perennial supply of water is derived. In the winter, while rain might be falling on the lowlands, snow would be accumulating on the mountains; in a summer drought the melting snow and ice would fill the rivers and provide abundantly for irrigation. In the Apennines, for instance, in the summer season the beds of rivers are frequently seen to be dry, though they are

swept for part of the year by strong full streams, as the pebbles which strew their channels sufficiently prove; yet in the Alps the Reuss pours into the Lake of Lucerne, and the Aar into the Lake of Brienz, a much larger quantity of water in July than in December. The Reuss in the summer months dashes down the rocky valley from Guttanen to Amsteg in a roaring turbid torrent, which it would be madness to attempt to wade; yet at the end of November I have seen its waters comparatively clear, and so much reduced in volume and force that here and there a strong man possibly might have stemmed the stream and crossed to the other side. As the snows melt, the waters rise; and thus the supply to the lowlands is increased at the time when it is most needed. Many a district now parched and arid would be rendered comparatively fertile by the addition of a couple of thousand feet to a neighboring mountain range.

Part II.

THE PROCESSES OF SCULPTURE AND MOLDING.

CHAPTER I.

THE WORK OF THE ATMOSPHERE.

THE earth's crust is constantly in a state of change. This is most marked at or very near to the surface, though it continues to considerable depths. But the agents of external and of internal change are sufficiently different to make a separate treatment convenient, so the present part of this book will be restricted, as far as possible, to the processes of earth sculpture—viz., those in which the agents of change act mainly, if not wholly, from without.

Air and water are Nature's principal carving tools. With the former changes of temperature may be considered; the latter may be conveniently separated into stream water—such as rain, rivers, floods; into sea water—that is, the action of waves and of marine currents; and into solid water—that is, the action of snow and ice. But Nature's work is not only destructive; if with one hand she pulls down, with another she builds up; in her economy transportation and deposition follow demolition. The substance dissolved from a rock is carried to some other place, and there either is precipitated or enters into new combinations; the fragment broken away from its surface is commonly borne along by some current, whether of air or of water, until at last it, or, more strictly speaking, a remnant of it, comes to rest, perchance hundreds of miles away from its original position. The work proceeds, "without haste and without rest," though in this place more quickly, in that more slowly, as the forces of Nature

> Draw down Æonian hills and sow
> The dust of continents to be.

Of the agents of change those directly connected with the atmosphere produce the most superficial effects, and require the briefest notice. First, as to those due to variations of temperature—the action of heat and cold. Obviously it is not easy in practice to separate them from certain effects of water, for the latter in freezing expands very suddenly, and exerts great force. Hence a low temperature produces much less effect upon a rock when it is dry

than when wet, and the latter condition is far the more common. Still in some countries the rocks, for all practical purposes, may be regarded as dry, and to the action on these the present chapter will be restricted.

When the surface of a rock is heated by the sun it expands; when the direct rays are cut off by a cloud it cools; it does this yet more when day gives place to night. Experiments have been made in order to obtain accurate measurements of the expansion produced by heat in different kinds of rock, and it has been found that sandstone expands more than marble, and marble more than granite, the coefficient for the first being nearly double that of the last.* As an illustration, it may suffice to say that the linear expansion of a mass of average rock corresponding with a rise in temperature amounting to 100° F. may be estimated as 2¾ feet per mile. This seems very slight, yet in a climate such as that of Rhode Island, U. S. A., it has been found practically impossible to make the joints of coping stones perfect. These constant changes in volume obviously must produce internal strains, which at last will almost certainly break the rocks. The strains will be more irregular and more likely to cause a fracture if one part of the rock is heated and cooled while the rest remains at a more uniform temperature. This is what occurs in Nature. The surface of a rock is most affected by heating and cooling; so that in regions where the changes of temperature are considerable these alone suffice to break up a mass, as travelers have frequently observed. To quote only one case as an example, it was remarked by Livingstone that in South Central Africa (lat. 12° S.), where the thermometer rose during the day to 137°, and fell by night to 42° F., the rocks were being constantly fractured by strain, sharp angular fragments being detached which weighed from a few ounces to a couple of hundred pounds. This is by no means an exceptional case; a range of 90° F. is not seldom observed in South Australia and in parts of Western America; in the former region it sometimes exceeds even 100° F. No doubt much of the loose sand and dust so abundant in arid desert regions in various parts of the earth is due to the same cause.

The heavier fragments lie where they fall. But the wind can

* Colonel Totten's experiments gave the following coefficients for each degree Fahrenheit: Granite, .000004825; marble, .000005668; sandstone, .000009532. These, and numerous determinations (generally rather smaller) by Mr. A. J. Adie and Mr. T. M. Reade, are quoted in the book of the latter, "The Origin of Mountain Ranges," ch. ix.

deal with the smaller. It is only on a calm day that the sand in a desert, or above the wash of the water on the seashore, is at rest. Before a brisk wind it is driven like a cloud. No long journey is needed to see this. Any sandy coast will show it. At Southport, for instance, in Lancashire, the shore is very flat and the sea retreats a long way, leaving bare at low tide a great expanse of sand. In a high wind the surface of this is almost hidden by a shallow drift—of mist, as it seems from a little distance—which, as it flows rapidly along, reproduces on a smaller scale the effect of a sandstorm in the deserts of Egypt. The grains, as they are hurried forward, keep on striking one against another. By this incessant abrasion their angles are gradually worn off, and they are converted into miniature pebbles. A handful of sand from the Libyan Desert, when examined with a lens, is seen to be full of rounded grains, while in that which has never been exposed to the action of the wind, such as ordinary river sand, hardly any of these grains can be found.

This, however, is not all; the grains not only impinge one upon another, but also are often dashed against projecting rocks. These, too, suffer from the incessant cannonade of those tiny projectiles. Nature made use of the "sand blast" long before man thought of availing himself of it for drilling and for engraving. When a retaining wall is built by the seaside, in the path of drifting sand, a few years suffice to smooth the roughened surfaces of the hewn stones. Loose blocks and projecting craglets on a sandy shore undergo the same treatment. For instance, near Burntisland, in Fifeshire, little knolls of basalt crop out from the sand. This, as it has drifted before the wind, has smoothed and even polished the hard rock. The surface, however, is not perfectly even, like one worn by the waves, nor is it grooved and striated, like one over which, as will be presently explained, a glacier has passed; but it is covered with small and extremely shallow hollows, in shape something like the bowl of a teaspoon, only longer in proportion, the narrower end pointing in the direction of the prevalent wind. This structure, however, is not always found; but wherever sand drifts over rocks, there the surfaces are worn. Sometimes, as in cases from African deserts, the exterior of some of the harder rocks is so completely polished that it appears as if artificially glazed; in others, where the material is soft, no inconsiderable masses are actually removed by the friction of the drifting sand. Projecting crags are worn into the strangest forms; recesses in the faces of cliffs are deepened,

possibly sometimes even excavated; pinnacles of rock are undercut till at last they topple over, as a tree when it is felled. In every desert region—in all four quarters of the globe, and in Australia no less—this process is going on. In Europe it is generally rare, still it may sometimes be seen, as in the strange forms of the Brimham rocks; but in such arid districts as the Libyan deserts, or the plains

FIG. 27.—WIND-WORN ROCKS, YELLOWSTONE PARK.

of Utah and Wyoming, the results are by no means unimportant, and drifting sand must not be excluded from the possible agents of earth sculpture.

But what becomes of the sand? Sooner or later it must find a resting place, though that may be only for a term of years. If a grain falls on any spot where it is sheltered from the wind, there of course it remains. So sand accumulates in hollows, valleys, sheltered recesses of any kind; some is blown into rivers, and is swept away by their currents. In sand from the Nile rounded grains are

frequent. These, however, are not formed by its stream, but blown into it from the adjoining deserts; some, again, is carried into the sea. But not a little accumulates on the land in drifts and dunes, the latter being the name commonly applied to low hills of blown sand. How these are formed is readily understood from Fig. 28, where the arrows represent the direction of the blast. The process, on a small scale, may be watched on the seashore on a windy day. Under the lee of any obstacle (*a*, Fig. 28), be it groin or post or

FIG. 28.—DIAGRAM SHOWING THE FORMATION OF A DUNE.

bowlder, a heap of sand gathers; even a tuft of grass may originate a tiny dune, hardly big enough to fill a tablespoon. A bank may also form, on the windward side, aginst a groin, or a wall, or anything long enough to arrest the advancing sand, which ultimately may overtop the obstacle and engulf it completely. Such dunes are accumulations on a small scale, but under more favorable circumstances they attain to a very considerable size. On the British coast the "sand hills," as they are commonly called, but seldom exceed 30 or 40 feet in height, and are limited in extent; but the dunes in some parts of the world are far more important features. In the deserts near Khokand they rise to about 100 feet.* "In the landes of Gascony a great many dunes exceed the elevation of 225 feet. There is even one, that of Lascours, whose long ridge, parallel to the seashore, attains 261 feet in several places, and raises its culminating dome to a height of 291 feet. . . In Africa, on the low shores where the ocean bathes the great Desert of Sahara, the enormous quantity of sandy materials that the eastern winds bring from the desert, and which the west wind drives back to the interior, permit, it is said, the dunes of Cape Bojador and Cape Verde to attain an elevation of from 390 to nearly 600 feet."†

In all dunes the slope which faces the wind is more gentle than that looking in the opposite direction. On the one side of the hill the mass in front affords a partial protection to that which lies

* Lansdell, "Russian Central Asia," ch. xxxiv.

† Réclus, "The Ocean," part i. ch. xxiv.

immediately behind it, but on the lee side the sand can rest at its natural angle of repose. "In the landes of the Gironde the western slope of the dunes . . . is, on an average, from 7 to 12 degrees. The eastern slope, which is that of the descending talus, is from 29 to 32 degrees; that is to say, three times as great."*

An isolated dune is generally crescentiform in plan. It takes this shape because its ends advance more rapidly than the middle part. Here the ridge is highest, so that the sand, as it travels up

FIG. 29.—BLOWN SAND ADVANCING ON CULTIVATED LAND, BERMUDA.

the one face and down the other, has a longer journey than it would have to make near either end. Thus even if the dune were to begin as a straight bank, with its crest rising from the sides toward the middle, it would, as it advanced, gradually assume a crescent shape, the convex edge, of course, being turned to the wind. "In the Desert of Atacama, the Pampas of Tamarugal, in the plains of Texas, in the Sahara of Algiers, in the Nubian deserts, and in almost all the regions traversed by shifting sands, the crescent-shaped dunes present such a regularity of form that all travelers have been struck by it. The landes of Gascony also offer remarkable examples of this semicircular arrangement of the crest

*Réclus, *Id.*, ch. xxiv.

of the dunes. In the environs of Arcachon and La Teste all these hillocks have the appearance of fallen-in volcanoes, and are distinguished by the rich vegetation of broom and bushes which fill their 'craters.'"*

As the dunes are formed of loose sand, they travel onward in the direction of the wind. Stronger blasts than usual sweep up some of the material from the exposed surface and drive it over the crest to fall down on the lee side. So their course is commonly land-

FIG. 30.—TOWER OF ECCLES CHURCH, A. D. 1839.

ward, and unless vegetation takes root upon the dune, and shields its surface from the wind, the fertile districts may be invaded by the onward march of the barren sand. In Bermuda gardens and woods are overwhelmed, and the dead trunks of trees may be seen projecting from mounds of blown sand. The coast of Norfolk, between Cromer and Yarmouth, offers a remarkable instance of the movement of a dune. Here, on the site of Eccles, a ruined belfry tower rises all alone on the strand. At high water it is only a few yards away from the margin of the sea. The walls of the church to which it was attached are gone; only the foundations remain, which are sometimes laid bare in places after a violent storm. There is now a smooth bank of sand where folk worshiped and were baptized, were married and were buried. Once the church

* Réclus, "The Ocean," part i. ch. xxiii. See also Lansdell, "Russian Central Asia," ch. xxxiv., liv. etc.

was surrounded by houses, once the village was inclosed by fields, but the sea has encroached, and as it advanced, the sand was blown up into dunes, which traveled onward as the vanguard of the invader. In the year 1839 the tower was buried, and its upper part projected from the mound; by 1862 it was all but clear;* in 1892 it rose from the level strand; the dunes had passed to its landward side, and their outer slope began a few yards from its base. Nature, however, does not leave these billows of sand to

FIG. 31.—TOWER OF ECCLES CHURCH, NOVEMBER, A. D. 1862.

encroach without making any effort to arrest their course. Plants there are which can thrive, especially in temperate climates, even on these arid wastes. On our own shores, and in many parts of Europe, the commonest and most useful is the marram grass (*Arundo arenaria*). Though its rush-like leaves cannot do much to arrest the wind, its long underground stems are able to hold the sand together. Thus aided, other plants also succeed in taking root, and the dune, by degrees, becomes covered with vegetation. Some trees, especially certain pines, contrive to grow, even to flourish, upon this dry sand, as may be seen in the pine woods of Arcachon, and the famous grove on the Adriatic shore, in the neighborhood of Ravenna.

In another way, too, the movement of sand is arrested, though

* The two sketches of the tower are repeated (by kind permission) from Sir C. Lyell's "Principles of Geology," ch. xx. I examined the locality in 1892.

this happens but seldom in the case of dunes. Water holding mineral salts in solution sometimes deposits them as it percolates through the mass. The process is initiated by some slightly favorable local conditions, but it may continue when once begun till the whole mass is cemented together like a bed of natural mortar. So solid does this occasionally become that the downward passage of water is completely arrested, and a swamp may be formed on the very spot which was once a dry plain of sand. This has happened in many parts of the landes of Gascony, but of late years extensive districts have been reclaimed by drainage, and rendered fertile.

But if sand is blown about, so also is much finer dust. The dry mud on the steppes around the Amu Daria, in the valley of the Yellow River and other parts of China, and in the Bad Lands of North America, is driven along in dark clouds, like the smoke from some vast furnace. The air is full of these almost impalpable particles, stifling man and beast, and the land is covered with the powder, often to a considerable depth. To this action some geologists of high repute have attributed a curious and widely distributed mud, which is called *loess* in parts of Europe. That deposit covers the natural features of the country like a pall up to a height of some hundreds, sometimes even thousands, of feet above the sea, occasionally accumulating in river valleys to so great a depth as a thousand feet.*

Dunes frequently exhibit a regular stratification of their materials, and false bedding can be produced by wind no less than by water, but obviously pebbles will be very infrequent constituents, and will generally be absent. As a rule, both these structures are found in sand hills. On the Picardy coast they can be seen from the train by the traveler bound for Paris from Calais; here certain beds occasionally project slightly, as they are more coherent than the others. Like structures often occur on the shores of Britain, and are no doubt universal, but they are sometimes a little difficult to find, because the last layer of loose sand hides all beneath it. Even where sections of dunes are made by storm, stream, or wave, the face of these is quickly concealed by the incoherent material slipping from above. Dunes, it may be added, are sometimes productive of change in a more indirect way than has been already mentioned. By their advance they may bar

* Richthofen, *Geological Magazine*, 1882, p. 293.

the course of a stream and force it either to change its path or to escape by soaking through the sand. In temperate climates the latter process very probably results in a marsh. Dunes may even dispute possession with the sea, and sometimes obstruct the openings of estuaries. Wind and water often struggle hard for mastery, but the former, in the long run, if it does not triumph, obtains a partial success by compelling the river to alter its course, and the sea to yield part of its territory. The mouth of the Adour, on the southwest coast of France, has more than once changed its position during the last three centuries,* and on the Gascon coast "the sea for one hundred miles is so barred by sand dunes that in all that distance only two outlets exist for the discharge of the drainage of the interior."† Thus, though the air is, in its action, the most superficial of the sculpturing tools of Nature, it is by no means inefficient, while the transporting powers of the wind are very far from inconsiderable. The lighter dust and the more tiny organisms which it has caught up are often carried to very great distances.

The strange, almost unearthly, glory that evening after evening in the late autumn of 1883 lit up the sky after sunset was attributed to the almost impalpable dust, ejected some months previously by Krakatoa, which was still floating in mid air some twenty miles above the surface of the earth. Dust falls on the decks of vessels far out at sea, and on the lonely wastes of snow amid the inland ice of Greenland. Placed beneath the microscope, it is resolved into tiny chips of mineral and rock. Who can venture to say how long the finer material ejected by a volcano or sucked up by a whirlwind may not float suspended in the atmosphere before it finally settles down again on the earth, or how far it may travel on its aërial course? The grain or the germ which has begun its journey on the steppes of Asia or the Bad Lands of North America, at the crater of Cotopaxi or from the cliffs of Chimborazo, may bring it to an end either on some lone oceanic island or in the heart of a crowded city.

* During the Middle Ages the lower Adour flowed parallel with the sea for more than twelve miles, and entered it near Cape Breton. Toward the end of the fourteenth century this outlet was blocked by a storm, and the river entered the sea some nine miles further north. The present outlet, partly artificial, is twenty-two miles to the south, near Bayonne.—Réclus, "The Earth," ch. lii.

† Geikie, "Textbook of Geology," book iii. part ii. sect. i. par. i.

CHAPTER II.

RAIN AND RIVERS AS SCULPTORS.

RAIN and rivers are Nature's most potent carving tools, running water is her most effective means of transport. Day by day, night after night, the tiny hammers of this numberless horde of nixies and cobolds never cease to patter on the rocks, their unblunting chisels to chip and hew. Before our eyes, though often they see it not, beneath our feet, though it is rarely perceived, her "construction trains" are running in a never-ending procession. This work began upon the earth before ever life was; it will continue so long as rain can fall and rivers can run.

Water exercises on rocks a twofold action: the one chemical, the other mechanical. It has also a twofold end: destruction and transportation, the latter commonly leading, directly or indirectly, to reconstruction. So far as may be—and this is not always possible—the processes shall be separately described.

First, then, in regard to the chemical action. To water no rock is perfectly impervious, by it probably none is wholly unaffected; through many it finds ready passage, on not a few acts as a rather quick solvent. The quantity of water which a rock can absorb before it is saturated depends upon its constitution, and, as might be expected, varies greatly. In some of the close-grained granites and basalts the amount is very small, varying from about one to three-tenths per cent. by volume—in certain limestones and sandstones it will reach even as much as thirty per cent.* Chalk ranks among the more absorbent of our English rocks. It is at once rapacious and miserly, quick and greedy in drinking up water, but very slow in parting with it. A piece of chalk 63 cubic inches in volume and 2 inches thick absorbed 12 cubic inches of water in a single minute and 26 inches in a quarter of an hour, being then perfectly saturated.† But when left to drain for 12 hours, it gave off only one-tenth of a cubic inch of water, and transmission was so slow that

* Building-stones of the better class range up to about fifteen per cent.

† Experiment by Professor Prestwich, "The Water-bearing Strata around London," p. 60.

when 8 square inches of its surface were kept covered with half an inch of water, only six-tenths of an inch filtered through the block. Yet the same quantity of sand, saturated with 22 cubic inches of water, gave off by drainage in the same time about 4 cubic inches, and afforded such a ready passage that water percolated through it at the rate of 3840 inches in the 12 hours. But the water as it passes seldom fails to levy a toll on the materials of the rock. Many of them are dissolved with comparative ease, especially when the water contains a small quantity of carbonic acid, as is usual with that which has fallen as rain or percolated through the soil. Geologists accustomed to the microscopic study of rocks are familiar with every stage of the process of decomposition. They know how one group of silicates, from being crystal-clear, becomes gradually tinted and ultimately opaque, like a mass of mud; how another changes its color, varies its optical properties, and assumes new forms; how the chemical composition of the rock, by a slow process of replacement, is at last so greatly altered that, for instance, a mass of silicates and oxides may become rich in carbonates. Basalt, one of the hardest of rocks, becomes comparatively soft; one of the blackest, it changes color—it turns to some shade of claret red or brown or green or gray, sometimes even to a cream white. Granite loses all its strength and solidity—the quartz, indeed, practically defies the foe, but as the strength of a chain is that of its weakest link; the mica yields, and the felspar, the most abundant mineral, changes to a clay. In Cornwall, in the Channel Isles, in Auvergne, in many parts of the world, the grains of quartz can be picked with the fingers out of the surface of the rotten granite; the mass can be dug with the spade to a depth of several yards. At Carclaze, near St. Austell, in Cornwall, huge pits, in which a village might be entombed, and perhaps even its church tower be concealed, have been excavated in search of tin ore and china clay. This, however, must be regarded as an exceptional case, for the corruption of the rock was probably brought about by the passage of mineral springs containing certain corrosive acids in solution rather than by the simple effects of rain water.

Constant dropping, as the old proverb runs, wears away stones. Rain, by chemical and mechanical action, leaves its mark on the surface of rocks. In the course of years the polish disappears from columns of marble or even of granite. The surface of the former rock soon loses all its gloss in large towns, where the rain is acidulated by the smoke of fires and the vapors of factories, though that

of the latter remains bright for many decades. Still even in the open country these effects are produced, though more slowly. At last the smoothed exterior of ashlar work becomes perceptibly roughened. The inferior varieties of stone, such as certain red sandstones, crumble away. The cathedrals of Chester and of Lichfield have been, to a great extent, refaced, the steeple of St. Michael's Church, in Coventry, has been completely incased in new ashlar work to save it from destruction, and the tower of St. John's Church, in Chester, became an actual ruin. Nothing can wholly withstand the action of the atmosphere and of the rain (aided, no doubt, by changes of temperature, especially by frost). The surface of the most durable sandstone becomes roughened. Even blocks of flint in the churches of Norfolk are dimmed and bleached externally, indicating that this most obdurate of rocks has been compelled to pay some tribute to Nature's solvent power. The "weathered" surfaces of rocks, as they are called, afford endless proofs of the same common action. Obscure structures, which sometimes are scarcely perceptible on freshly broken faces, are developed by the quiet, unceasing, yet delicate process of etching on which Nature's hand is ever engaged. About halfway up the northern face of Snowdon, near the bridle path leading from Llanberis to the summit, a mass of rock is passed which exhibits a number of thin wavy streaks of a grayish white tint projecting slightly above a darker surface. Yet if a fragment be broken off and a fresh face of the rock be examined this structure at a depth of a few inches is all but imperceptible. In other parts of Snowdon, on some of the hills of Charnwood Forest or of the lake district, fragments stud the outside of the crags, and indicate to the practiced eye that the whole mass is composed of pieces of lava and volcanic *débris*. Yet on a fresh-broken surface only a faint mottling reveals the variety of materials of which the rock consists. The same unequal weathering produces the roughened surface of granite, so welcome often to the Alpine climber, and contributes to the formation of every serrate ridge and towering peak. Nowhere is this effect more perceptible than amid the weird scenery of the Cuchullin Hills, in Skye, where the augite crystals sometimes stand out full half an inch from the weathered blocks of gabbro. By the same unequal action, more particularly in limestones, fossils are developed and the most delicate structures of organisms are revealed with a perfection to which the hand of man cannot attain.

The granite tors which, like ruined castles, crown the Dartmoor

hills are instances of the same process, where it has been carried a little further. Joints originally divided the rock into rude rectangles; of these the faces, and still more the corners, are attacked by the weather till they assume by degrees a more rounded outline. The smaller blocks rot away or yield to the weight above; portions of the mass fall, only the more durable resisting, so that the mountain peak becomes a ruin, no less than a fortress built by the hand

FIG. 32.—A GRANITE TOR ON DARTMOOR.

of man. Sometimes where one set of joints dominates still more curious forms are produced. A cliff near the Land's End looks as if built of sofa cushions, and one of the shoulders of Goatfell, in Arran, seems at a distance like a pile of feather beds. In some mountain regions, where thick masses of hard and evenly bedded limestone are traversed by very regular joints, the resemblance to ruined masonry is even more perfect. No better examples can be found than in the dolomite region of the Italian Tyrol, where the giant peaks often imitate with singular exactness ruined walls and "castled crags." (See Fig. 12, p. 23.)

Soil also, in many districts, is a record of the destructive action of water, for it is the insoluble or less soluble residue of a rock which has been destroyed. The top of a limestone hill is often bare, because, as the rock yields to the elements and disappears, the scanty residue is blown off by the wind, but on the slopes below it slowly accumulates as it is washed downward by the rain. At first a mere film is formed, on which only grass and scanty herbage can

take root, but at last this becomes thick enough to support a luxuriant vegetation, and even forest trees. The chalk downs, as in Sussex, present evidences yet more striking. In many places they are strewn with flints. Sometimes, no doubt, these are the remnants of old gravel, and are due to other causes; but not seldom the flints evidently have never taken a journey. They are merely the intractable residue, once interbanded with masses of chalk, which have been removed in solution. Nature's teeth are sharp and strong, but these are awkward morsels, so she has eaten the peach and left the stone lying about.

But the corrosive action of water is not confined to the surface; it can be followed up under ground. In parts of the valley of the Thames the chalk is covered by sharp quartz sand, which gives free passage to water. Between these two rocks a bed of flints, sometimes half a yard in thickness, commonly intervenes. The flints are exactly like those which occur as thin bands in the chalk below, except that they are coated with a kind of pigment of a dark green color. Geologists agree that the only possible explanation of this bed is to regard it as the residue of a mass of chalk which has been eaten away by the action of subterranean water. As the layers of flint are often separated by several feet of pure chalk, a considerable thickness of rock must be represented by this bed.

"Sand pipes" (Fig. 33) are another instance of the same process. These, though not restricted to the chalk, are better exhibited by it than by any other kind of rock. The face of a cutting in the chalk is often seen to be marked by a brown streak running downward from the top. This proves on examination to be a mass of sand and gravel. It may vary in diameter from some inches to some yards; it may extend downward into the chalk for a short distance, or it may run from the top to the bottom of the cutting; in form it may be almost as regular as a well shaft, or it may be curved or conical. In the early days of geology these singular pits were often attributed to the action of whirlpools, stationary tornadoes of water, drilling out the rock by the aid of pebbles; but to this hypothesis their abundance was an obvious difficulty, their occasional curved form, to mention no other objections, an insuper-

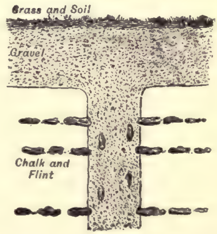


FIG. 33.—A SAND PIPE.

able obstacle. Closer examination showed that the stones in them frequently lay with their longer diameters pointing downward; that where bands of flint traversed the chalk unworn blocks of this material occurred at lower levels, also pointing in the same direction; and that the chalk itself on the walls of the pit showed signs of decomposition. These facts may be explained as follows: The chalk formerly was covered by a thick layer of sand or gravel. Through this water percolated; favored by some accidental inequality, such as a depression or small fissure, it attacked a particular part of the rock beneath, gradually dissolving a hollow; into this, as it was deepened, the material from above kept on slipping down. It assumed a pipe-like form, for the work of destruction would proceed at the bottom more quickly than at the sides. When a layer of flint was reached the descent of the mass for a time would be checked, but not the corrosive action of the water, for it would pass downward through fissures in the flint. So a kind of chamber would be formed beneath the layer, but after a time the roof would be crushed in by the weight above, and the pipe once more be completely filled. So the work went on. Commonly the gravel still remains on the top of the chalk, but in some cases it has been removed by natural processes, and at the present day these pipes are the sole indications of the mantling deposit which has been stripped away from the shoulders of hills.

Mineral springs, which will be noticed more particularly in describing the transporting power of water, are also indirect proofs of its solvent effect. They contain in solution various substances. But they must be fed by the rain, for a water factory is not likely to exist in the interior of the earth. Rain water, however, as has been already stated, is practically pure. So these mineral salts must have been acquired by the spring water in its passage through the earth's crust—or, in other words, the latter must have been deprived of certain constituents.

Similar testimony to the chemical action of water is borne by rivers. They are so largely fed by the rain that, even if allowance be made for the contributions of springs, their water should be almost pure. But this is not the case; some mineral salts are always detected, and a comparison of the analyses of specimens of water from different localities, as will be shown in the next chapter, indicates that the amount and the nature of the substances in solution depend on the rocks in the districts which are traversed by the rivers.

The mechanical effects of water are more obvious than the chemical. A heavy shower cleans a road from dust and dirt, fills the gutters with muddy water, strips the earth from banks. Even the raindrops, as they patter on the sand, leave their print in tiny pits. Sometimes these are covered up, so that the marks stamped by the

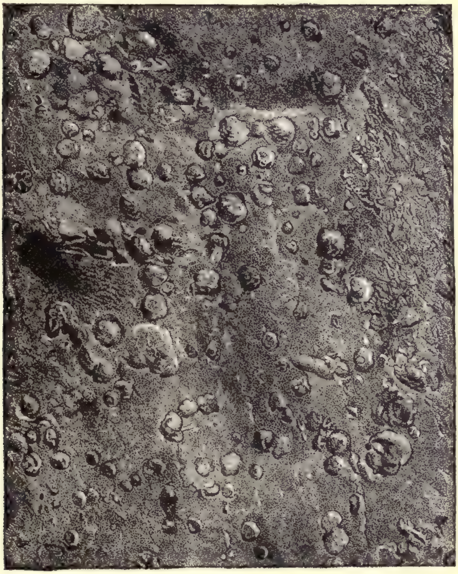


FIG. 34.—FOSSIL RAIN PRINTS.

passing storm may be preserved for countless cen.uries. In certain rock fossil rain prints (Fig. 34) are not uncommon, as in the Triassic sandstones at Grinshill, in Shropshire. Sometimes it is even possible to conjecture, from the shape of the cavity, the direction in which the wind was blowing, myriads of years before man existed. Even on the hardest rocks some effect is produced by rain, though years must elapse before this is readily perceptible. Its mechanical action is strikingly illsutrated by the tall pinnacles of stony clay which are called earth pillars. These may be found in several valleys of the Alps, the most remarkable being in the neighbor-

hood of Botzen, in the Italian Tyrol,* where they occur in the upper part of two valleys on a mountain called the Rittnerhorn. Valleys already excavated in the red felstone (commonly called porphyry) have been partially filled up with a tenacious clay which contains many pieces of rock, large and small. A glen has been cut by a mountain stream through the clay into the rock below, and on either side it is fringed by the earth pillars. The upper part of the glen, on the first glance, seems to be filled with these rude obelisks,

FIG. 35.—EARTH PILLARS ON THE RITTNERHORN.

crowded like tombs in an overfull churchyard, but on a closer inspection, a method is seen both in the order and in the shaping of the pillars. Now and then one stands alone; indeed, a solitary giant, more than thirty feet high, may be found† in the pine wood

*Other familiar localities are near Stalden, in the Vispthal, near Euseigne, in the Eringerthal, near the path from Viesch to the Eggischhorn, near Ferden, in the Lötschenthal, on the north side of the Brenner Pass, near Molines in Dauphiné (one about 70 feet high) near Sachas, in the same district, the last also sometimes 60 to 70 feet high, these being somewhat exceptional from the absence of capstones. (See Whymper, "Scrambles Through the Alps," p. 431, for a figure and description of the last.) Examples of the Botzen pillars and of that on the Eggischhorn are figured in Lyell's "Principles," ch. xv.

† At least, it could in 1880, but as it did not seem in quite such good repair as in 1872, it may be gone now.

rather below the first of the two valleys, but the majority are connected, and many of them form ridges of clay crested with pinnacles. Each is usually capped by a block of rock, like a turban; some, however, are bareheaded. On this block the existence of the earth pillar depends; those which have lost their caps lose, not their heads only, but also their bodies. Here and there the clay slope is furrowed by a rill, but for the most part the "nullahs" between the ridges and the gaps between the pillars are perfectly dry in fine weather. These, however, are wet enough after a rainstorm.

Three things become pretty clear to a geologist after a little scrambling among the pillars—that rain has cut the gullies, and even furrowed the sides of the pillars; that the larger stones are essential to their formation; and that the clay becomes very hard

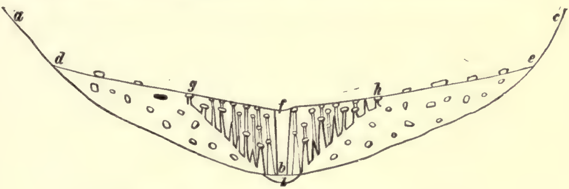


FIG. 36.—SECTION OF GLEN WITH EARTH PILLARS.
a, *b*, *c*, rock surface ; *d*, *g*, *f*, *h*, *e*, clay surface ; *f*, *b*, *l*, path of stream.

in drying. The process of sculpture was, roughly, as follows: The glen formerly was choked up with this stony clay; rills fed by rain worked away at its surface, and though the clay is hard when dry, it would quickly yield when damp to the friction of the water, and the mass be plowed into a number of furrows. One of these rills in deepening its bed would encounter a bowlder; this would at first check, then gradually divide, the stream; and at last, like a rocky island, would separate it into two currents, which, however, would again be united below. Each of these, after the manner of currents, would wear away the bank of clay which faced toward the stone, and would continue to work outward, even when its bed had been cut down below the level of the obstacle. Ribs of clay would be left between the rills, but as they would be attacked not only on both sides, but also from above by the rain, they would gradually disappear, and the capstones would remain exalted on pinnacles of stony clay. The rain, as their sides were exposed, would beat upon them, and do something, in trickling downward, to

reduce their thickness, but the pillar for a long time is protected from serious harm by the capstone, as by an umbrella. Still it is very slowly attenuated; the capstone becomes less and less firmly supported, till at last it slips or is blown off. Then the days of the pillar are numbered; from a pinnacle it becomes a hump, and at last is wholly washed away.

These earth pillars are due solely to the mechanical action of water, for upon clay of this kind it has no chemical effect of any importance. In the Alps they are seldom more than eight or nine yards high, and often rather less, but in America they reach a larger size. On the flanks of Mount Shasta they are gigantic. Mr. Clarence King speaks of a "family of pillars from one to seven hundred feet high, each capped with some hard lava bowlder which had protected the soft *débris* beneath from weathering."* But they may be seen also in miniature. Where there is a bank of clay containing some flattish chips of stone—such as may be found, not seldom, in North Wales—a careful search is almost sure to discover some tiny models of earth pillars, which perhaps may be as much as a couple of inches high, with capstones rather over half an inch in diameter.

But, as a rule, water acts both chemically and mechanically. Sometimes the one mode predominates, as in the making of swallow holes and caves; sometimes the other, as in the erosion of valleys and the general task of earth sculpture. But in cave and valley alike the stream is making its own bed, excavating its own channel; in the one case, however, this is a tunnel, in the other an open cutting.

On a wild upland moor near Ingleborough a stream has cut a channel, some half dozen yards wide, through the boggy soil and drift, down to the underlying limestone. This channel has reached a depth of some three or four yards, when its banks suddenly curve round, and it comes to an end, as the stream plunges into the limestone rock, down a vertical shaft.† Travelers are few in this lonesome place, or Gaping Gill, as the pit is called, might hide some grim secrets. Near the village of Clapham, rather more than a mile away, a pretty glen nestles between walls of gray limestone. On the right bank a cliff is pierced at its base by a natural archway,

* "Mountaineering in the Sierra Nevada," ch. xii.

† The mouth of the principal shaft (for there is a smaller one, concealed behind a bowlder) is about half a dozen yards broad and five yards long. The shafts unite ultimately, and the depth to the bottom is said to be 320 feet.

and some dozen paces further is a much lower and smaller opening, from which issues a copious stream. The former of these is the entrance of the famous Ingleborough caves, a series of galleries and grottoes which run for at least half a mile into the hill. They are the work of the stream, which for a time was checked on its downward progress by a bed of rock harder than usual, and forced to spend its energies on excavating these caves. But at last the floor was pierced, the water began to burrow through the softer rock below, and is doubtless now at work on a new set of galleries. The stream which has made the Ingleborough caves is the one which disappeared down Gaping Gill. This has been proved by various experiments, one of the most convincing being afforded by Nature. Some years since a violent storm broke over Ingleborough, and a torrent of water poured into Gaping Gill. After a time the stream which issued in the glen became swollen and muddy, till at last its channel was gorged, and the water rose up through hidden passages, flooded the caves, and then once more found egress through their portal. In the limestone districts of the western border of Yorkshire, of Derbyshire, and of Somersetshire caves traversed by underground rivers are common. The stream which flows out beneath the grand archway of the Peak Cavern is said to be the same as that which in the Speedwell mine plunges into a huge fissure, and is struck still higher up on its course in the caves at the Blue John mine. That which flows through the Wookey Hole Cave in the Mendips and emerges close by the famous Hyena Den has been swallowed up near the lead mine at Charterhouse.* The springs which bubble up in the gardens near the old cathedral at Wells so copiously as to make the moat of the bishop's palace a flowing stream—the springs which doubtless determined the site and gave the name to King Ine's church—restore once more to daylight water which has fallen as rain and has been swallowed up on the Mendip Hills.

Again and again proofs of the burrowing habit of water can be obtained in limestone regions. The process, no doubt, is partly mechanical, especially in the lower part of a swallow hole, where the stream must fall with considerable plunging force; but it is also

* This was proved in a curious way. A few years since the company that worked the mine took to throwing refuse down a swallow hole. Presently the paper made at a factory near Wookey Hole, which used the water, was spoiled, and the cattle which drank of the stream showed symptoms of lead-poisoning. A lawsuit arose, and the company was restrained by an injunction from thus disposing of the rubbish.

chemical, for caves are very rare in any but limestone districts. But in such districts even on the surface of the ground proofs of the corrosive power of water are easily found. The jutting reefs of rock, all pitted and pockmarked, the worn and rugged ridges, the cleft-like hollows, where in the Bernese Alps the holly fern puts forth its longest fronds, all tell of the corrosive work of water. In some parts of the Alps the surface of the rock is guttered with channels worn by the rain. On a bare mountain region in the Tyrol, called the Steinerne Meer, these channels are often only a foot or two apart, and each one ends in a vertical pipe, by which the rain is at once conveyed into the earth. So the surface of the rolling plateau is dry and desolate; only here and there a chance alpine herb succeeds in striking in some crevice or nestling in some cranny within the drip of the gutters. By unknown outlets, no doubt, the hoarded rainfall is again restored to the light of day. Springs are plentiful at the base of the crags, as the path drops down toward the silent waters of the Königs See. In some districts, as on the mountain south of Salzburg and near Hallstadt, the great limestone cliffs are almost riddled with mouths of small caves and of natural drain pipes. Sometimes a river can be followed for some distance under ground, like the Poik, which can be traced near Adelsberg under the mountains for almost a mile, or its presence is indicated more indirectly, as at the *dolinas* (swallow holes) in the same district, which for most of the year seem to be perfectly dry, but after heavy rain fill up and overflow, turning the whole plain into a lake, until the water again runs off through subterranean channels. The surface of all this region, in which the famous Adelsberg Caves are situated, and of the mountain range on the eastern coast of the Adriatic, where for league after league the same kind of limestone crops out, is singularly arid. Streams in other places burst full grown from the ground. So it is with the Manifold, near Dovedale, the Loue, and the Orbe, in the Jura, with the Siebenbrunnen, near the head of the Simmenthal, and many another. Even the Mole, in Surrey, is partially swallowed up, as is the Lesse, in the limestone district of Belgium, and the water from the solitary Daubensee on the Gemmi Pass goes swirling down some small shafts at the lower end as it does in the discharge pipe of a bath. Everywhere in the limestone regions, be they in any part of the earth—in Galway as in Derbyshire, in the Jura as in the Alps, in America as in Europe—swallow holes, underground streams, and caves may be found, from the mere rock shelter like the Victoria Cave at

Settle to the suites of subterranean halls at the Mammoth Cave of Kentucky.*

Valleys, from one end to the other, bear testimony to the erosive action of water. Formerly they were generally regarded as fissures, produced by movements of the earth's crust, and much ingenuity was expended in proving that the direction of the valleys in an upraised area corresponded with the rifts which would be caused by the strain to which it must have been exposed; but now it is generally admitted that while these and other consequences of earth movements may have produced indirect effects on the courses of streams, the rivers practically made the valleys, not the valleys the rivers.

Operations which Nature carries out on a grand scale are often reproduced and can be well studied on a small one, as in a model. A sand bank, as it drains dry after the tide has retired, exhibits, as in a map, a whole river system; the furrows plowed by a storm-burst in the slope of a sandy or gravelly moor repeat the outlines of a mountain glen. There is, in short, not a feature in the life history of a river which cannot be found by patient search in almost any district where the touch of Nature's finger is not marred by the hand of man. A river may begin its course in more than one way. Its history may consist of more than one chapter. Valleys there are which have been engraved, not on smooth hillsides or on almost level plateaus, but upon a surface already furrowed by an older system, in which, for some reason or other, the streams have ceased to flow and the erosive forces have changed their lines of action. In these cases the complete history can with difficulty be recovered. If a district, not once only, has been elevated above the sea and depressed below it; if the movements of upheaval and depression have not been uniform; if rock has been removed here and deposited there, the result may be a tangled skein of evidence very hard to unravel. Still even in such cases the history of the last and most conspicuous valley system can generally be determined. We may be in doubt as to the exact process by which the mountain peaks were originally defined, but we can generally trace out the history of most, if not all, the valleys. They often differ in

* Professor Shaler ("Aspects of the Earth," p. 109) estimates that "within a section of, say, ten square miles, and a thickness of 300 feet, in which lies the Mammoth Cave, there are probably in the known and unknown galleries more than 200 miles of ways large enough to permit the passage of a man, besides what is probably a greater length of smaller channels."

their origin. Sometimes the first stage is hardly marked, as when a stream begins from a snow bed or, as not seldom in our own island, from a boggy upland. For a time it trickles down, soaking through mossy banks or even sinking for a brief space into shelving screes. Then, as the rivulets gather together into a rill, and this acquires strength as it runs, it begins to furrow the slopes; a little lower down, perchance, some outcropping ledge rather harder than its neighbors for a moment checks the stream; it leaps this obstacle and strikes down upon the underlying softer rock. By this plunging motion a waterfall is begun (Fig. 37). If the slope be rapid, and the structure of the rock permit, the stream may descend in a series of leaps. But be the leap only that of a rill and for a few inches, or that of the whole St. Lawrence for the fifty yards of Niagara, the cause of the waterfall is the same—a harder ledge or mass projecting in the bed of the river and overlying some softer rocks. Sometimes, however, a glen has a more definitely marked beginning. When the shallow valleys on our English downs are traced up to their head they are often found to start from a bowl-like hollow. Its walls in some regions are rocky and steep, at times almost vertical. There exist natural apses, sometimes almost amphitheaters, on a large scale and on a small; the great corries in the Cuchullin Hills or in the heart of the Highlands, the huge "cirques"—recesses almost surrounded by precipices—such as Gavarnie and Troumouse in the Pyrenees, the Fer à Cheval or the Creux de Champs in the Alps—are often reproduced on a small scale in the beds of gravel, sand, and drift in our own country. Under the slopes of the East Binn at Burntisland some years since was a perfect model of a corrie; it was only four or five yards across, but illustrated completely the process by which such hollows are formed. The sides were furrowed by the rain runlets, which, working on the soft ashy rock,* had gradually excavated, as they converged toward a common center, this bowl-like hollow, from which their water had escaped by a single channel at the lower end. Sometimes, also, in the sands of Hampshire or of the Isle of

FIG. 37.—A WATERFALL.

* The hill is a mass of coarse ash or "agglomerate" connected with a very ancient volcano, the crater of which has long since disappeared.

Wight, the model of a cirque may be seen produced by the rills of rain. The larger corries and the greater cirques are the work of more powerful streams; those in the latter case are commonly fed by permanent snow beds resting on the upper ledges of the mountain. The strongly marked recesses are less common, both on the small scale and on the large, but almost every valley, if it does not actually die out on the hillside, ends in a more or less bowl-shaped hollow.

As the stream descends the mountain slope and increases in

FIG. 38.—DIAGRAM OF A CIRQUE, SURENEN PASS.

A, Peaks in clouds; B, limestone cliffs; C, shaly slopes ending in D, harder rock furrowed by streams; E, limestone cliffs, slightly grooved; F, talus heaps on floor.

volume, the glen deepens. Its shape depends on more than one factor, and hereafter must be considered in detail; for the present it is enough to say that, as the slope is regarded from a distance, the scar on its surface can be seen to widen and deepen, as if Nature's claw had been driven into the earth with ever-increasing strength.

Yet lower down streams unite their waters, and glens coalesce into a valley. That may become deeper, or it may become broader, according to circumstances; but glen joins glen and valley unites with valley, till at last their confluent waters sweep out into the lowlands. Then the hills retire, the river plain between them widens out, till in some cases all trace of a valley is lost. In fact, as will be presently explained, a river at last often ceases to erode and begins to deposit—instead of deepening it actually raises its bed.

The forms which a river valley may assume mainly depend on

two conditions: the erosive force of the stream—the joint effect of its volume and of its velocity—and the nature and structures of the rocks, whether hard or soft, whether homogeneous or the reverse, together with the directions of the dominant planes of weakness.

FIG. 39.—TERRACED CLIFF.
A, limestone; B, shale.

A rapid stream takes a straight course; a slow one meanders along in curves. If the fall be not less than ten feet a mile, the channel is perfectly straight; if the fall be only three inches, the path is a semicircle.* The windings of a little stream are frequent and small; those of a large stream may be measured by miles. In the bed of one of our flat English valleys a brook will make several twists in the compass of a single field, while in the channel of the Mississippi two points a few hundred yards apart by land may be separated by ten miles or more of river travel. Dealing first with the straight courses, if the stream be strong, the rocks hard and resistant, it cuts gorges. Such may be seen occasionally among the British hills, but here they are on a small scale; they are commoner and on a grander scale in the Alps. The gorge of the Visp near Zermatt, of the Trient near Vernayaz, in crystalline rocks, of the Tamina near Pfäfers (Fig. 41) and the Hinter Rhein at the Via Mala, in slaty rocks, of the Kirchet on the Aar and of Sottoguda near Caprile, in calcareous rocks, are among the finest examples. If the rock be homogeneous, and the planes of bedding, cleavage, or jointing neither too numerous nor inclined at too acute angles to the horizon, the cliffs will be straight and steep, the gorge almost like a fissure in the earth's crust—as once it was erroneously held to be. If, however, the rocks consist of alternate layers of soft and hard, the former will wear away more quickly, not only under the action of the stream cutting laterally, but also under that of the weather working upon the surfaces exposed in the walls. These, then, cannot remain vertical, but in receding assume a terraced form, crag and slope alternating in accordance with the characters of the beds (Fig. 39).

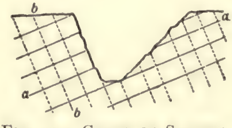


FIG. 40.—GORGE IN SLOPING BEDS.
a a, Bedding; *b b*, jointing.

Again, if the rock be traversed by divisional planes, a gorge can be cut so long as the blocks lie horizontally, because they are then in

* J. Fergusson, *Quarterly Journal of the Geological Society*, vol. xix. p. 321.

a stable position, like the stones in a wall; but if the planes slope to the horizon, the blocks are in this position on one side of the cutting only, on the other they will slip downward and fall: thus the cliff on one side of the gorge is nearly vertical, on the other it becomes a slope (Fig. 40).

Gorge-like valleys of some magnitude can be found in more than one part of Europe, such as Les Goulets, in the outer Alps, south-

FIG. 41.—THE GORGE OF THE TAMINA, PFÄFERS, SWITZERLAND.

west of Grenoble, and the valley of the Sarca below Tione, in the mountain district of the Brenta Alta. But no more wonderful instance of the erosive action of water exists on the earth's surface than that afforded by the cañon district of Colorado. The basin drained by this river is a vast plateau extending from the western side of the Rocky Mountains to the head of the Gulf of California. For nearly five hundred miles the river flows at the bottom of a gorge

from three to six thousand feet below the level of the plateau. The scenery, so admirably illustrated by the Geological Survey of America, reveals to the practiced eye a marvelous instance of earth sculpture. The traveler, as he rides across the plateau, may halt on the edge of a crag overlooking a broad valley.* Its floor is several miles wide; it is bounded by steeply terraced walls, some two thousand feet in height. Here they project in bastions or sharp salients; there outlying masses like ruined forts rise from the plain beneath. The plateau on either side is furrowed by valleys, some of them waterless, others still traversed by streams, all converging to this huge trench which is so like the dried-up bed of a river. This, however, on closer inspection is seen, like the plateau above, to be severed, but by a gorge, the walls of which descend yet more steeply than the escarpments bounding the upper trench, for they plunge down in places almost vertically for full three thousand feet. At the bottom flows the river—a swift, strong stream. These massive walls, like the escarpments above, are gashed, though yet more sharply, by lateral ravines, down which it is possible occasionally to descend to the level of the Colorado, but its waters not unfrequently for dozens of miles are quite inaccessible. The hunter might shoot a stag across the chasm, but it would take him more than a day's journey to get the venison. The formation of these vast gorges has been rendered possible by a combination of favorable circumstances. The whole plateau is built up of masses of fairly hard standstone and limestone, with but little of softer materials, disposed horizontally with curious regularity, like courses of Titanic masonry; and it rests on a foundation of solid granite, into which sometimes the river has cut a trench for as much as a thousand feet. The rainfall in the immediate neighborhood is slight, so that the elements can do little to destroy the edges of the trench and diminish the steepness of the walls; but it is heavy on the head waters of the river, for such a work as this could only be done by powerful cutting tools.

As a river begins to wind, a valley, as a rule, begins to change its outline. The erosive force of the water being diminished, the effects of the elements become relatively more important. The sides are no longer vertical, but begin to slope; the valley in a cross section takes the form of a V instead of an elongated U. This, however, is not all. It is but seldom that the two arms of the

* Such as appears in the upper part of the picture (Plate III.).

V are equally inclined to the horizon. Planes of separation in the mass of the rock may bring this about, as already described, but another and a more general cause is now at work. In all rivers the water at the surface moves more rapidly than that in contact with the bed, for friction checks its speed; the water in the middle outstrips that near the sides. But when a river winds, the median line of the channel only for a moment corresponds with that of quickest motion. Suppose, for instance, the course of a stream, represented by the lines P A R, Q B S, in the annexed diagram, to change at the points A B from a straight line to a curve, the line of quickest motion, which is parallel to A P, B Q, will pass through C, the middle point of A B. This line, below C, will not curve in correspondence with the banks so as to divide the space between them equally, but it will be nearer to the bank P A R than to Q B S, because, in conformity with the well-known law in dynamics, "a body in motion will continue in motion uniformly and

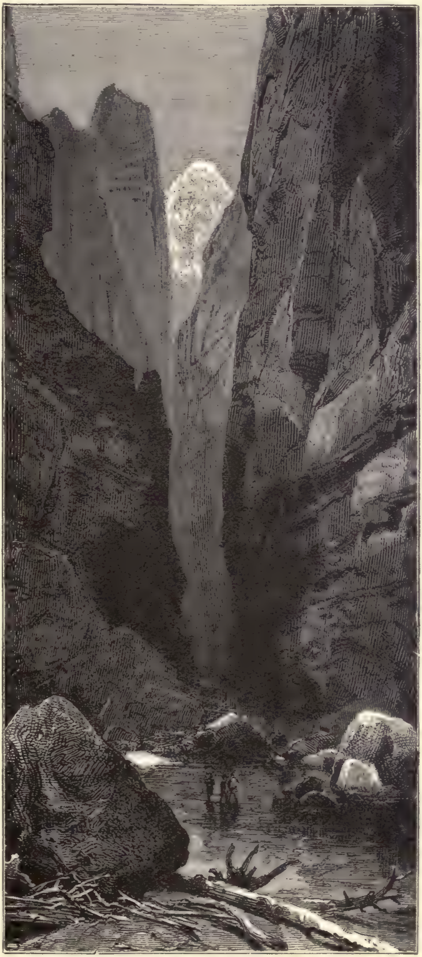


FIG. 42.—IN THE BED OF A CAÑON.

in a straight line until acted upon by some external force." So the line of quickest motion would continue to be a straight one were it not for the resistance of the bank P A R, and the curve, which it actually does follow, lies rather on that side of the channel. Thus beneath this bank the water flows more swiftly, and its erosive effect is greater than on the opposite side. In a winding river, as every boy knows, the water is deeper on the outer side of a bend—there he will find the best place for a header; on the other the bottom will shoal, so that a child might paddle on the one side of the stream while on the other he would be out of depth at once. So it is also with the valley. Its slopes descend steeply toward the convex part of the river: they shelve down more gently toward the concave side. As the river oscillates backward and forward, the deeper part of its bed changes its position from side to side; so also do the corresponding slopes of the valley. This is generally obvious enough. In England it is more conspicuous in the minor valleys; in those traversed by the more important rivers the water no longer occupies the whole breadth of the valley, but meanders over a flat plain, often taking a course altogether different from that which it followed when engaged in excavation.

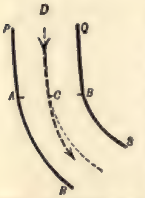
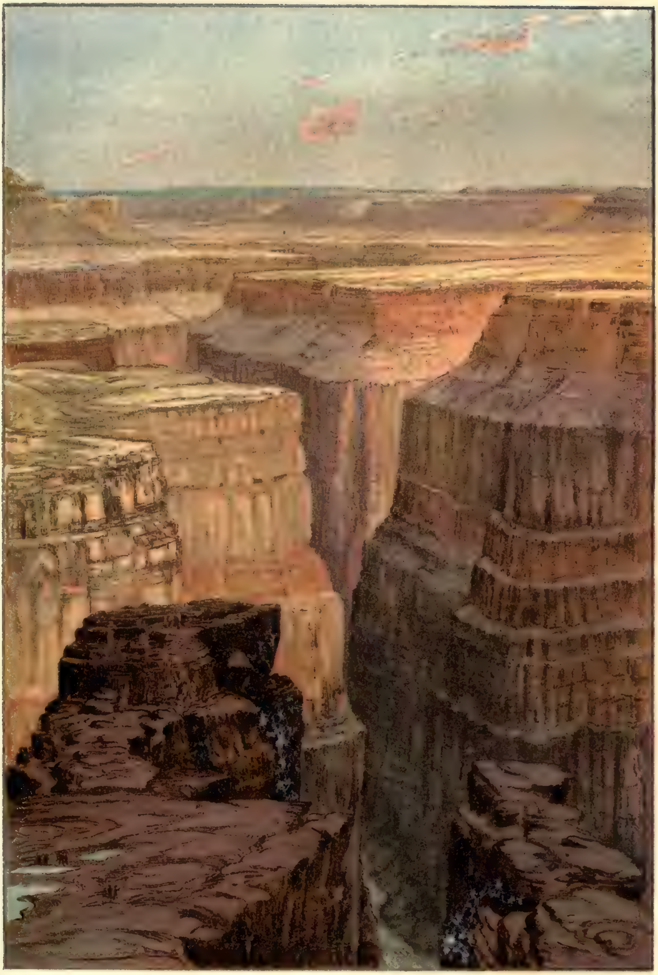


FIG. 43. DIAGRAM OF COURSE OF A RIVER.

The Meuse, in its passage through the Ardennes, exhibits some very striking illustrations of the connection of the slopes of a valley and the curves of a stream. Between Deville and Revin, two townlets on its banks, the river swings to and fro, forming three great loops, and carves a deep trench in a forest-clad plateau of slaty rock. The side of the valley facing the apex of one of these loops is nearly precipitous, and the woods descend almost to the level of the water, but the point of land thus encompassed shelves much more gently down, and is cultivated up to the level of the plateau. By following the serpentine curve of the river the steep and the gentle slopes may be seen alternating in correspondence from side to side of the valley. At Revin itself the town comes twice to the water side, for it extends across a neck of land perhaps 350 yards wide, while the river flows round a headland hill, making a journey of some 2½ miles. The current obviously presses upon both sides of this neck, and if man had not interfered by choosing this convenient spot as the site of Revin, the neck would ultimately be carved away and the river make a short cut by insulating the



BIRD'S-EYE VIEW OF THE CAÑONS OF COLORADO.

headland. In some countries where the river is strong and the rock is weak these "cuts-off" are not unfrequently found; the current, of course, abandoning the old channel, which thus becomes "dead water." This by degrees is separated from the bed of the running stream by the deposit of silt and by the growth of vegetation. These form a natural embankment, and convert the old course of the river into a horseshoe-shaped lake. "In the basin of the Mississippi, the Amazon, the Ganges, the Rhone, and the Po there are a considerable number of these circular lakes. We may trace out with the eye, as it were, three rivers, one of which, active and living, flows without interruption from its source to the sea, while the two others on either side are become 'dead water.' The remains of these, scattered all along the existing river, still point to the spot where once extended its ring-like windings. In consequence of the alternate shiftings of position, the valley is always much wider than its river, and along its circuitous path winds the continually changing bed of the existing stream. In some parts of its course the Po only takes about thirty years in forming and destroying each of its meanders."*

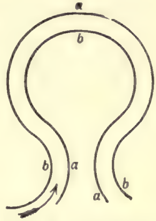


FIG. 44.—DIAGRAM OF WINDING RIVER.

In districts where the rocks are disposed in layers, and thick masses of fairly strong and homogeneous materials predominate, terraced walls characterize every valley and support every plateau. In the British Isles examples of this structure, except on a very small scale, can hardly be found. They are at their grandest in the Colorado district, as already mentioned, and in other parts of Western North America. In the Pyrenees, especially on the Spanish side, good instances may be sometimes seen; but perhaps the best, on the whole, in Europe may be found among the dolomite mountains of the Italian Tyrol. The Schlern, the Sella Spitz, the Rosengarten group, with other peaks of less fame, are excellent instances of the fortress-like masses which have been carved out of beds of rock which once extended over a much wider area.

Escarpments† are less obviously, but not less certainly, the

* Réclus, "The Earth," ch. xlix., where two plates are given, illustrating part of the course of the Mississippi, with its "bayous" or "cuts-off."

† This word denotes the steep or precipitous faces shown by a mass of rock as it crops out of the earth in a mountainous or hilly district. Obviously the crags of a terraced plateau are escarpments, but the term is generally applied to the less regular instances, where the beds do not lie horizontally.

results of the same erosive action of water. The steep face of the Cotswolds overlooking the valley of the Severn, the rapid plunge from the crest of the North Downs to the level of the Weald, are two among many examples. Formerly escarpments were supposed, like the "white walls" of England, to be the work of the sea, but it became evident, on closer examination, that this idea could not be maintained. When an escarpment is traced across the country, it is found to follow the outcrop of a particular bed of rock, and its face rises and falls correspondingly with any flexures in the latter. Not so with an old sea cliff. As a rule, its face remains at the same height above the Ordnance datum, and it cuts across different layers of rock in succession. In the case of the Weald, there is no reason to suppose that any part of it has been overflowed by the sea, except, perhaps, in the vicinity of the coast, since the time when its present structure was first defined. The whole valley, or rather the system of valleys, which make up this garden of Southern England, has been the work of fresh water in some form or other. Some time after the chalk was deposited the crust of the earth must have been slowly upheaved so as to form an egg-shaped dome, the longer axis of which extended at least from the western side of Hampshire to some distance east of the railway between Calais and Boulogne. As this mass gradually rose, its crest would be planed away by the waves; very possibly the chalk may have been wholly removed from its central part, and the underlying clay—called the gault—laid bare. No sooner had the waves retired from any part of the region than a new set of foes would rush to the attack, and its surface be worn by rain and by rivers. As the dome continued to rise, streams would run down its slope, and furrows be cut along the quickest lines of descent. But between the masses of more resistant rock, as, for instance, between the chalk of the Caterham Downs and the Lower Greensand of Nutfield ridge, and, again, between the latter and the hilly central district, lie thick beds of softer clay, which after a time would be exposed to the surface, even if they were not at first. On these the running water would act more rapidly; the rain which fell upon the areas between the main channels of drainage would be discharged into them by lateral streams. These would excavate a course for themselves in the soft clay, and thus catch the water from the adjacent slopes of the harder beds on either side. In this way lateral valleys would be formed, of which the floors would be deepened *pari passu* with those of the main channels, and the heads would be cut back into

the clay on either side until they met. As these valleys would descend very gently, their beds would be widened by the meandering streams, while those which radiated outward from the central part of the dome would be steeper, and so comparatively narrow. When a geological map of the Weald, on a small scale, is examined, the connection between its river valleys and its rocks is readily seen; but on the ground the minor irregularities due to the interference of channels, the changes in the course of streams, the action of the rain, and a hundred local causes of complication, often give rise to considerable difficulties in interpreting the structure. Still these diminish as the eye gains experience, and most of them yield to patient work, so that no reasonable doubt can exist as to the general history of the development of the physical features of the Weald.* In many places indications of the process of sculpture still remain, like workmen's tool marks in a deserted part of a quarry. There are old beds of gravel, often at considerable heights above the existing streams, with which in some cases they have no obvious connection. In the valley of the Medway, for instance, beds of gravel may be found at various stages up to a height of about 300 feet above the river. They indicate that the Medway formerly ran in the same general direction as at present, that its channel then was, perhaps, a hundred yards above that in which it now flows, and down to which it has gradually cut its way. But in order that the bed of the Medway could lie at the higher level the whole of the upper part of its basin must be correspondingly raised; in other words, all the land which it drained must have been well above the 300-feet contour line. A large part of this area is now 200 or even 250 feet below the level of the highest gravel; in other words, a valley "250 feet deep and 7 miles broad" has been cut out since that epoch by rain and rivers.† This conclusion once attained, there is comparatively little difficulty in understanding how the Weald as a whole has been excavated by like processes of denudation; and the more the face of the earth is studied, by passing from the lowlands to the highlands, from the plains to the plateaus, from the valleys to the mountains, the more strong becomes the conviction that rain and rivers are the most potent carving tools in the workshop of Nature.

* The severance of the eastern end from the main mass by the formation of the English Channel, as will be explained in a later chapter, is an event of comparatively late date.

† The history of the denudation of the Weald has been lucidly described by Messrs. Foster and Topley in a paper in the *Quarterly Journal of the Geological Society*, vol. xxi. (1865), p. 443, in which they give a sketch of the opinions advocated by early writers.

CHAPTER III.

RIVERS AS TRANSPORTERS.

WHEN the walls of Jerusalem rose again from ruin in the days of Nehemiah every man in the one hand held a weapon, with the other wrought in the work. So it is with all the forces of Nature—destruction, transference, rebuilding, form parts of a continuous process. Running water furrows the slope, it gashes the precipice, it shapes the crag, it excavates the valley. Not content with the work done upon the surface, it even mines and tunnels underground. But not a particle is removed by a stream from any part of its course which is not either actually transferred to a new position or at least held in trust—invisible, but available, like money on call at a bank—until it is required for use.

So the transporting action of moving water is hardly separable in thought from its destructive action; and the former, like the latter, operates both chemically and mechanically. These effects also, as in the preceding case, are not easily divided, but it is convenient to consider them, as far as possible, apart. If the chemical effects be discussed first, as in the last chapter, they are indicated by springs, especially by those called mineral. When water flows out of the earth either it must be supplied from some subterranean laboratory, where oxygen and hydrogen have been compelled to combine, or it must have percolated through the rock from the surface; that is to say, directly or indirectly it must be traced back to the rain. The former source is an improbable one; so it may be assumed that the water has fallen from the sky, has gravitated downward until checked by some impervious bed, has made its way along the surface of this, and has at last emerged at a level below that at which its journey commenced. If the water be traveling by percolation, it slowly trickles forth; if gathered into subterranean channels, it may gush out with considerable strength.

Rain water, as already said, is practically free from mineral salts, but in spring water these are always present; sometimes, it is true, in very minute quantities, but often enough to give it a marked character. Here, as at Harrogate, it seems to be seasoned with

rotten eggs; there, as at Stachelberg, it is yellow and stinks of brimstone; in many places, as at Bath, it has a "flavor of warm flat-irons," and leaves a universal trace of rust; in others, as at Droitwich, it is salt as brine.* Around the geysers of Iceland and of the Yellowstone district mounds of opaline silica are raised which

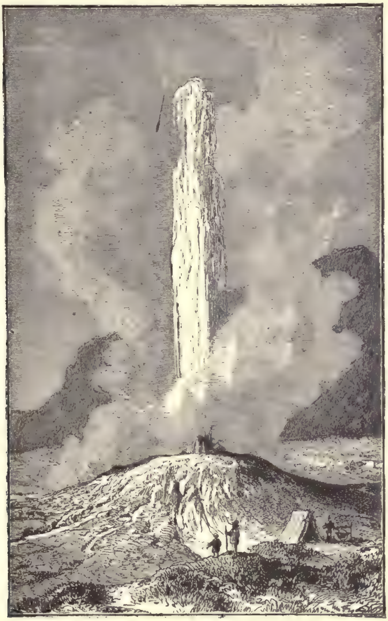


FIG. 45.—GEYSER AND MOUND OF SILICA.

imitate the craters of volcanoes (Fig. 45); the white and pink terraces of Rotomahana, now counted among the world's lost wonders,

* The result of pumping brine (which is formed by the solution of beds of rock salt in the percolating underground water) at Droitwich is thus described: "As we pass through the town by the Birmingham and Bristol line of the Midland Railway a strange scene of dilapidation lies before us. Every chimney is out of the perpendicular; houses appear to be sinking in, and signs of active subsidence show themselves on every side; the very ground over which the line passes seems hardly safe from a sudden collapse" (C. Parkinson, *Quarterly Journal of the Geological Society*, 1884, p. 248). The effects at Northwich, in Cheshire, are even more disastrous. The brine at Droitwich and at Stoke contains from 38 to 40 per cent. of solid matter, 42 being the saturation point of common salt.

were built up by similar deposits from the hot springs of New Zealand (Fig. 46). Chlorides, sulphates, and nitrates of soda and potash, salts of iron and of lime, are among the more frequent products of mineral springs, all of which are obtained from or found among the constituents of the earth's crust, and can be separated from it by water, especially if this be slightly acidulated, as it is generally, as a result of the decomposition of organisms.

The mineral character of the rocks which have been traversed mainly determines the nature and quantity of the salts. In limestone districts the water of wells and springs, as every housewife knows, is hard—that is to say, contains a considerable quantity of bicarbonate of lime. This compound, which consists of two molecules of carbonic acid in combination with one molecule of lime, is soluble in water, but not so the carbonate—just as a weight might be floated by two bladders which would sink with one. The bicarbonate is an unstable compound, or, to carry on the simile, one of the bladders is attached by a thin string which is easily broken. So when the water evaporates, either from heat or from exposure to the air, one molecule of carbonic acid is detached and the carbonate of lime is precipitated. Thus pipes, kettles, and boilers are "furred"; the roofs of caverns are hung with stalactites, or stony icicles; their floors are covered with stalagmite, a natural pavement formed and laid down by the drip from above; below the mouths of springs great banks of limestone, called tufa or travertine, are slowly deposited. These may be seen, to take one example out of many, in the valley of the Derwent, at Matlock, below the "petrifying wells," where eggs, birds' nests, and sundry objects are incrusted, and find sale among visitors who have a liking for curiosities; but at some places, such as Clermont Ferrand or St. Nectaire in Auvergne, more artistic results are obtained, for the water is made to flow very gently over a number of molds, and the carbonate of lime thus deposited makes very pretty casts. At the former place a small natural bridge has been built across a stream by the deposit from the water which runs away after it has been utilized at the factory. Huge banks of tufa are formed, according to Tchihatchef, by the deposit from the hot springs near the ancient Ionian city of Hierapolis; this also has spanned a little valley with a bridge, quaint but picturesque.*

Rivers also testify to the solvent power of water. As they are

* A figure of this is given by Réclus, "The Earth," ch. xli.

Fig. 46.—Terraces at Rotomahana.

partly fed by springs, this is to be expected, but the quantity of mineral matter held in solution is often too great to be explained only in this way. It must also have been obtained by the streams as they were excavating their sub-aërial channels and wearing rock-fragments into pebbles, sand, and mud. It will be enough to quote three analyses of river water, out of the many which have been published, to show how large a quantity of mineral salts, comparatively speaking, is carried in solution, and how much this depends upon the character of the rocks in different districts. In the water of the Scotch Dee, near Aberdeen, the solid matter in solution amounts to 3.12 parts by weight in a hundred thousand, of which 1.22 consist of carbonate of lime. The proportion in the water of the Rhine, above Bâle, is 17.12, of which 12.79 are carbonate of lime and 1.54 sulphate of lime. But in the Thames, near Ditton, the proportion is 27.20, of which 16.84 are carbonate of lime and 4.37 are sulphate. Thus in these three rivers the amounts of carbonate of lime alone are as the numbers 122, 1279, and 1684, or, as a rough estimate, the Thames transports in solution a third as much again of this mineral as the Rhine, and fourteen times as much as the Dee. This disproportion is readily understood on investigating the geology of the areas drained by these three rivers. In the basin of the Dee the rocks are but rarely calcareous, and consist almost exclusively of silicates, which are with difficulty soluble in water. The Rhine and its Alpine tributaries flow partly over similar rocks, partly over limestones; these, however, occupy a much larger share proportionately of the drainage area of the Thames.

The immense quantity of material thus transported, by a river which counts as a small one among those of the world, may be more readily appreciated by another mode of representation. It has been estimated that the Thames, as it flows under Kingston Bridge, carries in solution, on an average, about 1514 tons of mineral salts in the course of twenty-four hours. Of this about 1000 tons is carbonate of lime. A ton of chalk is a mass measuring about 15 cubic feet, so that 15,000 cubic feet of chalk—in other words, a block 10 feet square and 150 feet long—slips invisibly past Kingston; enough, in the course of a year, to cover the whole area of Westminster Abbey with a solid mass of limestone nearly 9 feet high.

But not in this form only is matter transported. The bed of every torrent is strewn with bowlders and gravel, that of a quieter stream with sand and mud. By listening at the side of a swollen

Alpine torrent we can hear the bigger stones groaning and thudding as they are rolled along; we can see the water in every stream at flood time thick with suspended silt. If a river flows at the rate

FIG. 47.—MAP OF VOLCANIC DISTRICT, ROTOMAHANA.

of 300 yards an hour, it can just wear away and move along soft clay; with double that speed fine sand is transferred; as the velocity increases so, rapidly, does the size of the materials, and when it attains to a pace of 4800 yards, or about 2¾ miles an hour, pebbles an inch and a half in diameter are swept along. The first rate is that of slow-flowing rivers, such as those in the fenlands of Holland or of Eastern England; the last more nearly represents

that of the great European rivers, such as the Rhine at Bâle, or the Danube at Vienna.* A considerable quantity of finer detritus, as said above, is also carried by the quicker streams at all times, by the slower during a flood. This moves in a state of suspension in the waters, like dust in the air, the coarser stuff being swept by the stream, as by a besom, along its bed. It has been estimated that the Rhine, even when its waters are low, transports sediment to the amount of 1 part in 7000 by weight; but the proportion rises to 1 in 2000 under ordinary circumstances, and reaches 1 in 230 at flood time. The Ganges and Brahmapootra are said to discharge annually into the Bay of Bengal about 40,000,000,000 cubic feet of sediment. This, at a rough estimate, might be piled up in a pyramidal hill measuring 4 miles along each side and in height 300 feet. The Ganges alone is believed to bring down sufficient mud to cover 172 square miles with a layer 1 foot thick. Suppose this material formed into a similar hill, with its base covering a square mile, this would be 516 feet high. But the Ganges is beaten by the Mississippi, for its pyramid would rise to 804 feet; while the Hoangho works yet harder to fill up the Yellow Sea, for the pyramid formed of its detritus would tower up to 2190 feet.

Some of the materials thus transported by a river are not carried very far. No sooner is its velocity checked than the coarser stuff is deposited. Shoals form in rivers in the stiller water at the junction of cross currents and against the convexities of the banks. If a narrow strip of level ground chance to occur by the side of a torrent in an Alpine glen, this is a stony waste of bowlders, which have been dropped there in times of flood. Where the glen enters a main valley, and its waters are discharged into the latter from a slightly higher level, as happens at many places in the valley of the Rhone, between Martigny and Brieg, the bowlders and gravel, mixed with sand, which have been successfully swept down the steeper inclines, are at once piled up in a "cone of *déjection*" or an "alluvial fan." These sloping mounds of *débris* before the entrances of lateral glens are common features in the scenery of a mountain region like Switzerland. They may be readily recognized in that beautiful view of the Rhone valley which is obtained on the descent from the Baths of Leuk to the village of the same name. In the Rocky Mountains, the Himalayas, and other great chains these

* This would be the maximum velocity. In a fairly rapid river the minimum velocity is to the maximum, roughly, in the proportion of 3 : 5 ; in a slow one as 1 : 2.

"fans" are many miles in diameter and hundreds of feet in thickness. But, besides this, the beds of the larger mountain valleys are being continually raised by the *débris* which is deposited in them during floods. At such times much of the coarser material does not rest upon the cone, but is hurried on and spread out over the level floor of the main valley.* The plateau of La Bâtie between the Rhone and the Arve, below Geneva, is a thick mass of gravel; from its pleasant walks the opposite cliff overhanging the former river is seen to be wholly composed of irregularly stratified beds of sand and pebbles, which have been brought down by the Arve from the mountains of Savoy. The lowlands, for miles around Bâle, consist of similar pebble beds, the deposits of the Rhine and its tributaries comparatively late in their geological history. The plains of Piedmont and Lombardy are one widespread mass of gravel, the *débris* of that vast mountain wall which sweeps around the whole basin of the Po.

A delta is only another, and a yet more complete, proof of the transporting power of running water. When a river enters a lake or falls into the sea, the velocity of its current is at once checked, and the deposit of detritus is correspondingly rapid. In the Alpine lakes the muddy and the clear water are sometimes very sharply separated, the one being suspended in the other, like a cumulus cloud in the blue sky. This can be watched as it rolls obliquely downward into the clearer depths, in the same way as smoke drifts upward into the air. Sometimes the division between the two is so sharp that the bow of a boat may be in clean and the stern in turbid water. But, in any case, on looking down upon the embouchure of a river from one of the hills above an Alpine lake an area of discolored water can be at once detected—in outline a rude triangle or parabola, the apex pointing away from the shore. The mud sinks slowly to the bottom, drifting along with the gently moving water, so that the materials must be to some extent sorted. Much of it descends at rates varying from ten to four feet an hour, but the finest particles settle down still more slowly, and may be many months in reaching the bottom, if, indeed, they ever come to rest. The turquoise tint of the water in many lakes is due to these, and even the exquisite blue of the Rhone as it issues from the Lake of Geneva is attributed to the presence of suspended par-

* The effect of floods is often checked by banking in the stream, but this, of course, only alters the form of the area over which the *débris* is deposited, and produces other consequences, which will be presently described.

ticles of almost inconceivable minuteness. The water beneath the walls of Chillon has a different tint from that which flows by Rousseau's Island; the water of the Lake of Brienz is more distinctly green than that of the Lake of Thun, because the Aar empties itself directly into the one and only the Lutschine into the other.

At the Rivington waterworks, which supply Liverpool, a delta estimated as containing 6306 cubic yards was formed in one of the reservoirs in twenty-seven years by the stream from a gathering ground not quite one square mile and a fifth in area, on which the average rainfall was 49½ inches.* In the same period the Reuss had deposited in the Lake of Lucerne† a delta estimated to contain more than 141,000,000 of cubic feet, which would be equivalent to a daily deposit of 19,350 cubic feet, or a solid block 50 feet long, 43 wide, and 9 high. The lakes of Thun and Brienz formerly must have been one sheet of water. They have been divided by the detritus brought down on the one side by the Lutschine from the glaciers of the Oberland, on the other by the Lombach from the lower summits of the Habkerenthal. The openings of the valleys are about a couple of miles apart, so the delta of the Lutschine first forces the Aar to graze the base of the Harder at Interlaken; then the river is driven over to the southern side, as it comes within the influence of the delta of the Lombach. Yet the depth of the basin in this part must have been originally between seven and eight hundred feet. The level plains which extend for some miles up the valleys above the heads of the Alpine lakes are all deltas which have been formed by the detritus brought down by the rivers. To take a single case as an example of many: Once upon a time the Lake of Geneva must have extended up to St. Maurice, where a rocky barrier forms the portal of Canton Valais. From that spot to Bouveret on the present shore is a distance of about fourteen miles. From the margin of the land the water at first deepens very slowly, the face of the mass of *débris* shelving gently down to a depth of nearly a thousand feet. Its total length may be estimated at about ten miles. But immediately opposite to the actual embouchure the current of the river has still sufficient influence to interfere partially with the deposit of *débris*, so that down to a depth of about eight hundred feet a deep inlet is formed in all the contour lines. Egypt, to quote the old saying, is "the gift of the Nile," and the same is true in other parts of the world. The deltas

* T. M. Reade, *Quarterly Journal of the Geological Society*, 1884, p. 263.

† A rectification of the course of the river had been made.

formed when rivers fall into the sea are proofs of their transporting power, but on a much grander scale than in the case of lakes. Here, however, a new influence is brought to bear, that of the tide, so the description of such deltas as these is better postponed to a later chapter.

The general effect of floods has been already mentioned, but one or two particular cases demand a brief notice. As the nature of some people is wholly changed in a fit of passion, so the character of a stream may be completely altered in a time of flood. The rill may become a river, the purling brook a roaring torrent. This of course will only happen after an exceptionally heavy fall of rain, but such an event now and again occurs in regions where, as a rule, eccentricities of climate are rare. On the night of August 2, 1879, full four inches of rain fell at Cambridge between about eight o'clock in the evening and four o'clock in the morning. By nine o'clock a little brook which drains a shallow valley some four miles long, and usually creeps at a snail's pace through the grounds of St. John's College to the Cam, had become a swift stream, and had laid under water much land on either side of its banks. In two or three hours more, when the Cam became similarly swollen, all the lower ground in the valley was flooded, and the water came up to within about a couple of feet of the crown of the arches at one of the bridges.

But the floods in a lowland region, though sometimes mischievous and making a great mess with the mud and gravel which they are apt to distribute over cultivated land, are comparatively unimportant. In rivers which issue from mountain masses, especially where the slopes are steep and the valleys contracted, the stream in a narrow part of its channel may rise forty or fifty feet, and cover many a square mile where it debouches on the lowland. The floods of the Garonne are often exceptionally disastrous. In the year 1875 one rose, even at Toulouse, to a height of some thirty feet, and swept away two suspension bridges. Frequently, as we traveled over the country, broken bridges were seen. Sometimes a pier was so completely destroyed that only a break in the surface of the stream indicated its place.

Occasionally a flood is so much localized as to call for a special notice, since the result is rather exceptional. In the month of July, 1887, part of the level bed of the Ziller-thal, in the Tyrol, presented a melancholy spectacle. A mass of *débris*, consisting of black mud mingled with blocks of rock sometimes several cubic feet in volume,

had swept across from the foot of the mountains, burying cornfields and meadows, brushwood and gardens. Through this scene of ruin a little stream, only a few inches deep and perhaps a couple of yards wide, ran rippling toward the river. Yet this seemingly harmless rill had wrought that devastation, destroying two houses, and utterly ruining many acres of good meadow land. Its course down the mountain slopes is comparatively short, but the rocks through which it has furrowed a channel are friable, and easily swept away. Exactly over this place a violent storm had burst; just for an hour the stream had become a raging torrent, a foaming mass of black mud and rock fragments, and this was the result. The rubbish lay two or three feet deep in the open part of the valley, some hundreds of yards from the slopes, and the bowlders not seldom were three or four feet in diameter.

Sometimes, under very exceptional circumstances, a flood may be even less liquid than the last described, and a mass of mud emerges from some mountain recess, like a glacier of exceptional filth and softness. Such an one in the year 1835 descended from the Dent du Midi to near Evionnaz, in the valley of the Rhone. The coarse thick mud, mixed with bowlders, slowly crept down from the mountain side, sweeping through a pine forest "as if it were straw in a stubble field," destroying houses and burying cultivated tracts. The high-road was covered for about a furlong, and to a depth, in places, of several feet.

Landslips also may be counted among the effects of water, though here its action is mainly indirect, for it does little more than initiate the catastrophe, and the transport of material is due to gravitation. The conditions for a landslip are the following: At the top must be a thick mass of rock, through which, though fairly strong and hard, water can make its way; beneath this a bed rather less coherent in nature; and below that a third, which is impervious to water. These rocks also must be disposed so as to slope slightly outward to the face of a cliff or of a steep hillside. After a rainy season the middle seam becomes saturated with water, and its materials are rendered less coherent. It yields to the pressure of the overlying mass, which at last begins to glide downward, like a building of which the foundations have been sapped. When once it has broken loose from a hillside, the mass, like the stone of Sisyphus, "thunders impetuous down and smokes along the ground." Landslips on a small scale are not rare on some parts of the English coast. Thus has been formed the beautiful Undercliff

in the Isle of Wight. The chalk and the cherty beds of the Upper Greensand rest upon less coherent materials, and these are supported by the impervious blue clay called the Gault, all the beds sloping toward the sea. From time to time great masses have slipped forward from the face of the range of hills which culminates in St. Catherine's Point, plowing up the clay, and breaking up as they descended into smaller fragments; so that the whole presents a scene, geologically speaking, of the wildest confusion. Similar slips occur frequently on the Dorset coast, west of Swanage, but the most noted is to be found between Lyme Regis and Axmouth. Here the cliffs rise to a height of full a hundred feet, and the general arrangement of the strata resembles that in the Isle of Wight. Small landslips are common, but the greatest on record occurred on December 24, 1839, after an unusually wet season. Then a deep chasm, nearly three-quarters of a mile in length, almost instantaneously opened out in the fields at the top of the cliff, parallel with the shore, and the intervening strip of land, sometimes a hundred yards wide, slipped forward toward the sea, breaking up as it went into a number of large fragments.*

In mountain districts these landslips are yet more formidable, and have frequently wrought much destruction to life and property. Hundreds of acres of fertile lands may be buried deep beneath a wild waste of broken rock and tumbled crags. One instance may serve as an example of many; and no better could be found than the noted case of the fall of the Rossberg, the ruins of which are now crossed by everyone who travels along the St. Gothard railway from Lucerne toward the valley of the Reuss. The thick bed of hard pudding stone which forms the upper part of the Rossberg, as well as of the better known Rigi, rests, as described above, upon a less coherent mass, from which the water cannot readily escape. On the morning of September 27, 1806, at the end of a very wet period, which had lasted for several months, a large mass of the pudding stone, after some brief preliminary warnings, suddenly broke loose and fell, shattered into fragments, on the devoted valley. Huge blocks of stone were hurled through the air, reaching across the flat meadows to the lower slopes of the Rigi, and in a few minutes a large tract of populous and fruitful country was

* After the above paragraph was written another instance was added to the list by the landslip at Sandgate on March 4 and 5, 1893. This, however, was rendered noteworthy, not so much for the magnitude of the mass displaced as for the destruction of property, since part of the town was built on the ground which slipped.

hidden beneath a mass of ruin. The village of Goldau and three neighboring hamlets were covered with confused piles of rock and earth from 100 to 200 feet in thickness, under which they still remain buried. Of the inhabitants 433 lost their lives, as well as 24 strangers. According to a rough estimate, the portion of the mountain that fell measured a league in length, a thousand feet in breadth, and a hundred feet in thickness.*

In these cases, however, the transporting effects of water, though locally important, are limited in extent. Here, as elsewhere, the rule is observed, which holds generally in Nature, that the intensity of the disturbing action, and the area affected by it, are roughly in inverse proportions. The surface of the earth is modified by the ordinary action of rain and rivers far more than by the exceptional fury of deluges. It loses and it gains by the almost silent and imperceptible transfer of material through the water which streams from every slope and flows away in silent strength from every mountain system, which glides through the lowlands and finds at last its bourne in the sea, far more than it does by the rush of mud avalanches or by the rage of cataclysms.

* Ball, "Alpine Guide, Central Alps," § 26 C.

CHAPTER IV.

ICE AS SCULPTOR.

WATER is converted into ice when its temperature falls below 32° F. As the fluid becomes a solid, its volume increases largely and suddenly, 1000 cubic inches of water making 1102 cubic inches of ice. The force possessed by the expanding mass is very great. This has been strikingly illustrated by an experiment made many years since in Canada, which has been often repeated, under slightly different conditions, in laboratories. A bombshell of the old pattern, about 13 inches in diameter and an inch in thickness, was filled with water, and the touch hole tightly corked by a plug weighing 3 pounds. The shell, with its contents, was then exposed to the severe cold of a winter night. In a short time the plug was projected to a distance of 415 feet, and a tongue of ice, as it were in derision, was protruded from the orifice. The experiment was repeated, but this time the plug was too tightly fixed to be ejected, so the shell itself was split.

The bursting of water pipes in houses, so common in a severe frost, supplies the tenant with an object lesson, the plumber with work, and the cynic with another characteristic example of British unwisdom, which cannot be taught to provide for any but the most ordinary contingencies. Similar object lessons are yet commoner outside than they are inside the houses. After a hard frost which has followed on damp weather the pointing drops out of the joints of walls, and the bricks, especially in the jerry-built structures of the nineteenth century, crack and crumble away. Even the surfaces of rocks scale off in flakes, sometimes several pounds in weight. In a railway cutting through any rather porous rock these flakes may be often seen in plenty lying in the gutter at the foot of the walls. Beneath a cliff they are strewn in like manner, though here their history is less readily recognized by an inexperienced eye. Nevertheless, the talus, or sloping bank of angular fragments, which is usually present at the foot of a cliff, has been formed—at any rate, in a climate like that of England—mainly by the expansive effect of water in freezing, though no doubt mere alterations of

temperature, as already explained, have also taken part in the work. The flanks and summits of mountains often tell the same tale. The stone avalanches which thunder down their precipitous slopes are started by frost, and mainly consist of blocks detached by the action of ice. In some places the discharge during the day is almost incessant, but it does not wholly cease at night. On such a peak as the Matterhorn the sleeper in the upper hut will probably be awakened three or four times by the roar of the stony cataract down the eastern face of the mountain, and instinctively presses closer to the shelter of the crag. Rocky and lofty summits are not seldom natural cairns: blocks poised, not always too securely, one on another, so that it is not easy to be sure where the live rock begins. In Arctic regions, as described by travelers, the rocks are often completely shattered by the frost. The crags in winter, as it were, burst asunder with a loud report; huge masses are detached, which sooner or later tumble down upon either the frozen shore or the surface of the ice.*

But frozen water does not only play the part of a wedge, it acts also in the form of snow and glacier. The latter is more local in its operations than the former, but its effects are the more distinctly marked. Snow falls when the temperature of a considerable layer of moist air sinks below 32° F. If the temperature continues low, the snow does not melt, but gradually accumulates. In such a case it is commonly ineffective as an agent of denudation; indeed, as the temperature of a thick layer of snow does not readily fall much below 32° F., such a layer acts like a cloak in protecting the surface of the earth from a severe frost. But in one case disturbances may be produced. In Britain, when a thaw begins, any snow resting upon a sloping roof is apt to slip and scale off suddenly, the event being announced by a heavy thud—sometimes by a crash of glass, if a greenhouse has been built below in a convenient position. In like manner the snow slips away from the mountain side in great masses, called avalanches. These sometimes consist of powdery snow; such are called in the Alps "dust avalanches." They may happen at any time soon after a heavy fall of snow, before the mass consolidates and unites itself with the surface below. Others of greater consistency are called "ground avalanches." These are formed of the snow which has lain long on the mountain side, and

* "Nordenskiöld's Arctic Voyages," ch. iv.; H. W. Feilden, *Quarterly Journal of the Geological Society*, 1878, p. 564.

fall when the spring is advancing and the warmer weather is beginning to set in. They are on a larger scale than the others, consisting of thicker and more solid masses, and in consequence are the more destructive. They sweep a path clean through the smaller or more open pine woods, snapping the boles off short or uprooting the trees; they tear up turf and bushes and stones from the hillside, and either strew the slopes below with *débris* or hurl it into the valley, where the piled up snow often lingers long into the summer months, and sometimes may be seen completely bridging the torrent. But ice is more potent as a scuplturing tool in the form of a glacier. In brief outline the history of "a river of ice," as it has been sometimes called, is as follows: A place some height above the sea level, as already said, has a lower mean temperature than one by the water side; for instance, the mean annual temperature of Fort William, on the west coast of Scotland, is 46.8° F.; at the observatory on the summit of Ben Nevis it is 30.9° F. This indicates a fall of 1° F. for each 277 feet of ascent, which is rather exceptionally rapid. As the change is very dependent upon local circumstances, it is difficult to fix upon a normal rate of fall, but about 1° F. for each 300 feet of ascent is probably not far wrong.* Thus, even under the equator, the mean temperature of the upper part of a great mountain is below 32° F. The lofty volcanic summits of the Ecuadorian Andes are thickly clothed with perennial snow, and even give rise to occasional glaciers. The isothermal of 32° is at the sea level some little distance south of Fredrichshaab, near the southern end of Greenland, but on the peak at Ben Nevis it is at an elevation of about 4100 feet, over that of Snowdon at about 5500. In the Alps the position of the isothermal of 32° varies from about 7500 feet above the sea level, as in some of the more northern districts, such as the Sentis, to rather more than 8500 feet in the more southern, such as round the Viso.

Closely connected with the isothermal of 32° F. is the snow line, a term which indicates the frontier between the lower zone of a mountain, where the fallen snow always disappears from the surface, and the upper zone, where it can lie permanently; or, in other words, the line where, in respect of snow, income and expenditure for the year just balance. This line, as a rule, lies somewhat above the isothermal of 32°; the difference, however, will be probably

* Perhaps even this is a little under the mark. In the Alps it seems to vary from the above rate to about 1° F. for 330 feet.

rather less than 700 feet. Above this line the snow naturally begins to accumulate in favorable situations, and a glacier may be formed, as already described.* This creeps down the valley, the rate of motion depending upon a variety of circumstances. Its pace is quicker in summer than in winter, and seems to depend partly upon the size of the glacier. In those of the Alps the rate of motion is about 365 feet a year, but the great ice streams of Greenland advance from more than twenty to even fifty times as fast.† In all cases the middle part of a glacier, as with a river, moves more rapidly than the sides, and the top than the bottom.

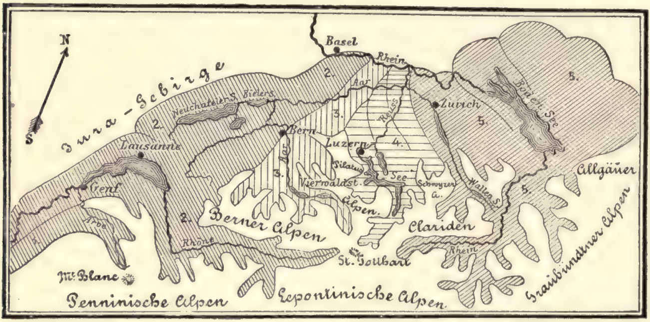


FIG. 48.—SKETCH MAP SHOWING FORMER EXTENT OF ALPINE GLACIERS (N. SIDE).

By this differential motion the mass is thrown into a state of strain, especially near the sides; and as a result large crevasses are formed, as already described.

As a glacier moves downward its surface gradually melts. At the commencement of its journey it may be augmented occasionally by fresh falls of snow, but this supply constantly diminishes, while the rate of expenditure increases as the glacier moves down the mountain side. To what distance it can descend—whether it can last long enough to trespass upon the lowlands—must obviously depend upon the magnitude of the area from which its supplies are drawn and the distance to be traversed. In the Alps, where the snow line is at nearly 8000 feet above the sea, glaciers of any importance seldom form unless a considerable area or "feeding ground" rises for more than 1000 (commonly at least 2000) feet higher. The greater glaciers are fed by large snowfields, which extend up to from 10,000

* See page 70. † See page 73.

to 11,000 feet, and receive further supplies from peaks rising yet higher by from 2000 to 4000 feet. The great Aletsch glacier, the largest in Switzerland, is surrounded by a jagged line of peaks, even the lowest gap in which is above 10,000 feet. Glaciers come to an end in the Alps at from 3500 to 5000 feet above the sea. It must be understood that these figures are only rough approximations—local causes of variation are so numerous that any very precise statement is impossible; indeed, any one glacier is liable to fluctuations which are not unimportant. Since about 1860 the glaciers of the Alps have been diminishing in size. This has retreated along a comparatively level bed for several hundred yards, that has retired up a slope and terminates 400 or 500 feet above its former end. They have also lost correspondingly in thickness. Their period of diminution appears now to have ceased, and for the last two or three years most of the Alpine glaciers have been slowly advancing.

As the ice is melted by the heat of the sun, the water collects into rills, which furrow the surface of the glacier and sometimes form considerable streams. These sooner or later are engulfed in a fissure and make their way beneath the ice till they are gathered at last into a single torrent, which is augmented by streams descending from the slopes on either side, and finally issues from a cave at the end of the glacier. Thus the rock beneath the ice may be carved into glens. The engulfed stream, as it plunges downward, often drills a vertical shaft through the glacier, and the waterfall, aided by blocks of stone which have been accidentally swept into the depths, wears out gigantic potholes in the rock below. So these remain long after the ice has melted away from a surface of rock, and are among the most certain indications that a glacier has once passed over the place. Wonderful examples of these potholes, called by some persons "giants' kettles," were discovered in making an excavation near the noted Lion monument of Lucerne. Here, close together, are several huge hollows in the soft sandstone rock, the largest being about six yards deep and eight wide. Bowlders a yard or more in diameter still lie within them, the pestles which once ground out these gigantic mortars (Fig. 49).

As the glacier moves down a valley it abrades the rocks beneath; its surface is armed by fragments broken from projecting ledges, by stones which have fallen down crevasses, and by the finer powder which has been either worn away from the underlying rock or derived from the crushing of chips. Grist never fails in a mill like this, but very much of it comes from the nether millstone. The

effect of a glacier upon the rocks over which it passes may be compared to that of a file or of sandpaper. By degrees all prominences are removed, and the rough, often jagged, outlines characteristic of ordinary weathering are replaced by rounded billowy surfaces, "like the backs of plunging dolphins." But a more homely comparison may be made, and one which long ago commended itself to inland folk, who were more familiar with flocks than with cetaceans. The outline of these iceworn rocks is frequently not

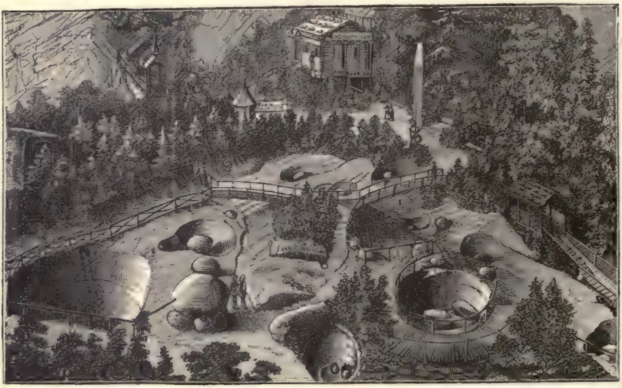


FIG. 49.—BIRD'S-EYE VIEW OF POTHOLES IN GLACIER GARDEN, LUCERNE.

unlike that of the backs of sheep as they are lying down, and from this the name of *roches moutonnées* was given (Fig. 50). The surface at times is worn quite smooth, even polished; but as Nature is rather careless about the quality of the putty powder, her work is constantly marred by scratches from the coarser particles. Grooves, and even shallow channels, are occasionally worn out by the passage of larger stones, so that the aspect of a district from which glaciers have retreated,* after it has been once seen, is readily recognized; their "handwriting on the wall" is generally so plain that he who runs may read. It may be noticed again and again among the Scotch, the Cumbrian, and the Cambrian Highlands; it can even be discovered on the lower slopes of Arthur's Seat, on the

* Other signs there are, such as moraines, but as these result from the transporting, not the erosive, force of a glacier, a description of them must be postponed to another chapter.

limestone rocks in Morecambe Bay, and above the cliffs of the Northumbrian coast. There was a time, to be described more fully in a later chapter, when glaciers flowed down every valley of the Pyrenees and trespassed on the lowlands of Southern France, when they buried deep the sacred cave at Lourdes and the rock crowned

FIG. 50.—"ROCHES MOUTONNÉES"—THE GRIMSEL.

by the pilgrim church. Then also, between the Alps and the Jura, instead of lake and forest, cornfield and vineyard, was one wide field of ice; for the glaciers from the valley of the Rhone welled up against the slopes of the Chasseron above the Lake of Neuchâtel (Fig. 48).

But if a glacier can abrade, can it also excavate? This question during the last thirty years has greatly exercised the minds of geologists, and it is one of such general interest as to call for a brief sketch of the arguments on both sides. Members of one school

attribute great excavatory power to a glacier; they point confidently to the subalpine lakes as its handiwork. They have even cast longing glances at those huge sheets of water in North America which are drained by the St. Lawrence. Members of the other concede no more than some slight excavatory action under exceptional circumstances.

The subalpine lakes were claimed as results of glacial excavation by the late Sir A. Ramsay in the year 1862.* Starting from the admitted fact that these lakes are true rock basins, and within areas once occupied by ice, he disposes of sundry explanations which had been previously offered. They cannot have been excavated by the sea; they are too deep to have been worn out by the currents of the rivers which flow through them. If it is urged that they are gaping fissures in the earth's crust, the impossibility of this hypothesis is at once demonstrated by a section across their beds, drawn on a true scale—for the sides slope comparatively slowly down, and the deepest part sometimes is almost a plain. They are on too large a scale and too numerous to make it probable that they have been results of local subsidence caused by the removal of underlying beds by any process of solution—like the little meres formed in Cheshire when the ground sinks as the rock salt beneath is liquified and carried away in the brine springs; nor can they be explained as basin-like depressions—great shallow dimples on the face of the earth—formed by the bending down of the strata toward a common center, in which water has accumulated as in the hollow of a mackintosh cloak, because no such structure can be detected around them, and it can be shown that the direction of the lake is often transverse to the strike of the outcropping beds. As these explanations are unsatisfactory, and no other of like kind suggested itself to the author, he maintained that the lake basins must have been made by something which was able to grind and scoop. This, he argued, a glacier can do, as it rubs down its rocky bed, if it presses with greater force on certain parts, and thus wears out trough-like hollows, the form of which is modified by the geography of the glacier and the geological structure of the district. In confirmation of this view he called attention to the fact that tarns and lakelets are abundant in regions such as Scandinavia and parts of Scotland, Wales, and Northern America, over which it is universally admitted that glaciers once flowed; and these are often true rock basins,

* *Quarterly Journal of the Geological Society*, 1862, p. 185.

analogous to, though on a much smaller scale than, those of the subalpine lakes. The explanation was extremely plausible; it was undoubtedly supported by a certain number of facts, and the other hypotheses which were cited had been completely overthrown. It was soon received into general favor, and still counts many adherents. But even in the hour of its greatest popularity it was steadfastly opposed by a smaller number of geologists. Veterans like Lyell and Murchison looked askance at it; men exceptionally familiar with the Alps, like the late John Ball, like Ruskin, and others, suggested serious difficulties. It was asked: If glaciers were able to excavate basins, long as Como and Maggiore, great as Geneva and Constance, deep as Thun and Lucerne, or, in places sheltered by lower mountains, as Zug and Lugano, how was it that the beds of the valleys, from the heads of the present lakes to the feet of the existing glaciers, were not full either of tarns or filled-up lakelets? or, at any rate, did not present in cross section the outline of broad troughs, like the letter U, such as would be planed out by a gouging tool like a glacier? What, then, are the facts which are learned by a careful study of the Alpine valleys above these lakes which are the subject of dispute? Wherever its rocky bed is exposed to view it is found that not only are tarns rare, but also the slopes on either side descend with comparative steepness to the level of the torrent; or, in other words, the V-like section characteristic of river erosion is everywhere present. Yet rocks striated and rounded by glacial action abound, and can be often traced to within a few feet of the water, showing that the contours of the district have not been materially changed since the ice melted. The glacier, as it has been said, "has all along been 'indentured' in a groove, but it has been a thoroughly idle apprentice, till some cause, no more permanent than the master's stick, has quickened it into intense but brief energy." A glacier in its descent of a mountain valley seems to have produced effects which are, comparatively speaking, superficial; it has rasped away prominences, and made rough places smooth, but as an excavator it has been a failure, for if rocks projected in its path, it flowed past the higher or over the lower, like a river by the pier of a bridge or over a bowlder in its stream; nay, sometimes it has not even removed out of the way loose material, but has crept lumbering above it.* The tarns so

* In one case, at the back of the town of Como, it was so exhausted with the effort of excavating that arm of the lake, and climbing afterward up the hill, that the crest of soft sandstone over which it flowed still remains comparatively sharp and unworn.—*Quarterly Journal of the Geological Society*, 1874, p. 485.

common in many mountainous districts, which the disbelievers in extensive glacial excavation are willing to concede to the action of ice, can be shown to occur, almost invariably, either at the foot of steep slopes, as in the bed of a corrie on the mountain side, where a somewhat plastic substance like ice would of necessity scrape with considerable force upon the rocky floor below, as the angle of descent was changed; or else behind barriers and narrow places in the bed of the valley over which the ice had been forced, where it would act in a similar way, scraping upon the rock behind the obstacle. Lastly, the opponents of the excavation hypothesis pointed out that in his discussion of its rivals Sir A. Ramsay had strangely overlooked one alternative—viz., that the lakes might have been formed by a subsidence, not local, but general, affecting a considerable district parallel with the average trend of the mountain range. To this none of the objections which had been advanced could apply. His critics maintained that the subalpine lakes were portions of valleys which had been previously excavated in the usual way during the long period when the Alps were rising and being sculptured; that at a time geologically recent the same forces as had produced the mountain ranges, by wrinkling and doubling into parallel folds a portion of the earth's crust, had again operated, developing a comparatively slight flexure, which affected the level of the floors of the valleys. These, at one place, may have been slightly pushed up; further back they may have curved gently downward, bending the sloping floor into a hollow, in which water would gradually accumulate as the subsidence progressed. An examination of a geological map of the Alps indicates that the majority of the lakes can be grouped in zones connected with the trend of the ranges, like Orta, Maggiore, Lugano, Como, Iseo, etc.; and if the question be asked, Why, if this be the true explanation, has not every Alpine valley a lake near its mouth? the answer may be returned that the subsidence was not necessarily uniform, and that, as it is, where a lake is wanting a stony plain usually occurs to mark where one formerly existed. As these lakes would not be of uniform depth, those which were the more shallow, or received a greater quantity of *débris*, would be silted up, for an extensive delta has been formed at the head of every one of the lakes, and is gradually trespassing on the water. The careful study to which, of late years, some of the Alpine lakes, such as Constance, Lucerne, Zürich, and Geneva, have been subjected, has shown that the subaqueous contours of their basins correspond with the subaërial,

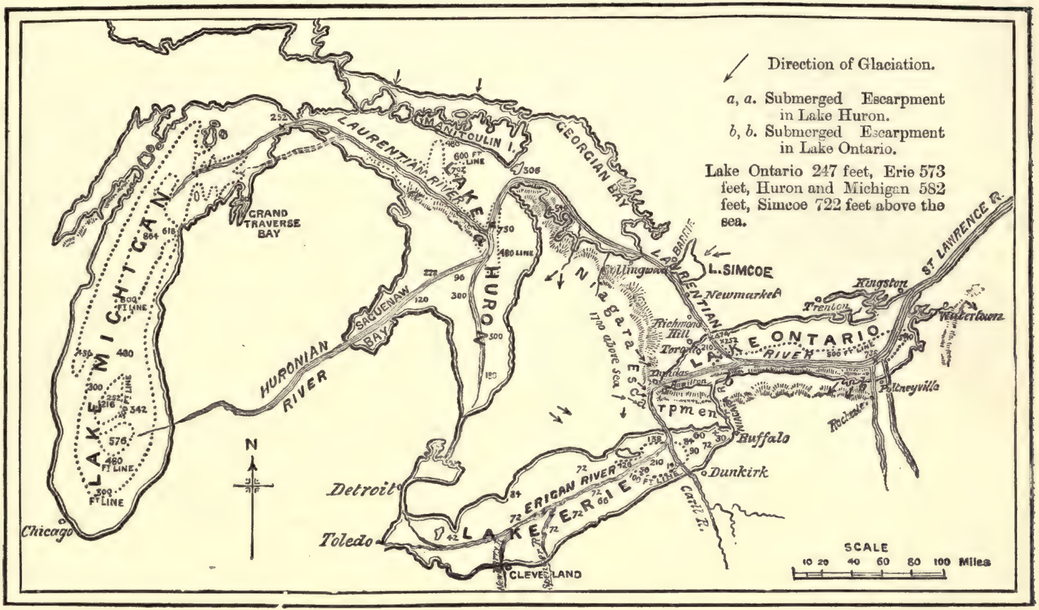


FIG. 51.—MAP OF THE GREAT LAKES OF CANADA AND THE UNITED STATES.

instead of being smooth and featureless, as should have been the case if they had been scooped out by a glacier. It was pointed out from the first that as it was impossible to attribute such lakes as the Dead Sea, the Victoria and Albert Nyanza, Tanganyika, with others in similar situations, to the action of glaciers, some other method of forming rock basins on a large scale must exist, so that ice was not left as the only possible alternative; and of late years the work of American surveyors and geologists around the great lakes of Canada and the United States has proved to demonstration that these, though within a region once glaciated, form a submerged valley system, the upper basin of the St. Lawrence having subsided relatively to the lower. Here, as elsewhere, the *débris* left by the melting ice has probably helped in raising the level of the water by blocking up old channels of drainage. Lake Michigan, for instance, is found to be divided by a subaqueous watershed into two basins, the more southern of which formerly communicated with Saginaw Bay on Lake Huron by a channel, now buried under drift, but still to be traced eastward across the broad peninsula between the two sheets of water. The diagram (Fig. 51), reprinted by kind permission from a most important paper by Professor J. W. Spencer,* will indicate the facts more clearly than any verbal description.

Thus it appears to be proved that though the effects of a glacier are undoubtedly considerable, it acts like a plane or a file rather than a chisel or a gouge. Hence it excavates only under exceptional circumstances and to a limited extent. The tarns in mountain corries, the lakelets in mountain valleys, may be attributed to the action of ice, but not the broad sheets of Geneva or Constance, the deep glens of Brienz and Thun, or the radiating arms of Lugano and Lucerne.†

In all speculations as to the effect of glaciers in past epochs of the earth's history it must not be forgotten that their magnitude in any region depends primarily on two conditions, the one being the amount of precipitation, the other the area of land within the

* *Quarterly Journal of the Geological Society*, 1890, p. 523.

† It must not be understood that lakes can only be formed by the two operations discussed above. Some (not usually of large size) occupy the craters of volcanoes; others have been blocked, by lava streams, by moraines, by the *débris* of a torrent, or by landslips. Some may be formed partly in one way, partly in another. Indeed, it is probable that the level of certain of the Alpine lakes is somewhat raised by partial blocking of their effluents by *débris*.

snow line. The neighborhood of Hudson's Bay, or of Yakutsk in Siberia, is free from glaciers, because the snowfall is light, though the climate is so severe that a fairly thick stratum of permanently frozen ground is struck at a few feet below the surface; while on the western side of the New Zealand Alps, notwithstanding the comparatively moderate elevation of the chain and the mildness of the climate,* the glaciers occasionally descend to within less than a thousand feet of the sea level, and considerably lower than they come down on the eastern slopes, because of the heavy precipitation from the vapor-laden winds which blow from the west. On the great mountain chains which separate Hindustan from Thibet the glaciers, notwithstanding their aspect, are not nearly so large on the northern side as on the southern, because, as the vapor-laden air is traveling from the latter quarter, precipitation takes place mainly on that side. Even in the Alps a comparatively small difference of geographical position produces a marked effect. For instance, the Gross Glockner is slightly lower than the Viso, and the heads of the valleys around the two mountains must be nearly at the same level;† yet the one is the culminating point of a glacier system, the other only overlooks some permanent snowbeds.

* Mount Cook, the highest peak, is 12,349 feet above the sea, and there are several others about 11,000 feet. The mean temperature at the sea level is roughly 55° F.; the snow line, therefore, should be at about 7500 feet, or not very different from its level in the north of Switzerland; but there is a large area just above it, and the precipitation on this is very heavy, so the glaciers are relatively much larger than in the Alps.

† Probably in this respect, or at any rate in regard to the crests of the ranges, the Glockner district has a slight advantage.

CHAPTER V.

ICE AS A CARRIER.

GLACIERS, like rivers, act as agents of transport, though to what extent is a matter of dispute. Rock *débris*, small and large, is carried upon the surface, is embedded in the ice, is pushed along between it and the bed of the valley; so that, even in this respect, a certain analogy exists between a glacier and a river. As to the amount transported in these three ways, geologists are practically agreed upon the first, differ little about the second, but are very much at issue over the third. The reason of this is that the first is a matter of direct observation, the third is largely one of inference, while the second partakes of both.

As a glacier glides slowly on between the rocky slopes of a valley, its surface is strewn with *débris* which either tumbles from the crags above or is swept down by avalanches. The fallen materials consist sometimes of dust, small stones, and bowlders, but occasionally masses occur which can be measured by cubic yards, and may be as big as a small cottage. As a rule, they come to rest quite near to the edge of the ice, and so form a kind of rocky selvage to the ice stream, by which they are slowly swept onward. These accumulations of broken *débris* are called moraines, and in such a position are distinguished as "lateral." (Fig. 52.) Not seldom much of the material is speedily stranded, forming a bank at the side. When two glens combine their ice streams and form a single glacier the right hand moraine of the one unites with the left hand moraine of the other. Thus an embankment of broken rock is formed in the middle part of the glacier, and on that account is called a medial moraine. Obviously the number of medial moraines will be one less than that of the confluent glaciers. Beneath this rocky covering the ice melts much less rapidly than when it is exposed to the heat of the sun, so that the moraine, after a time, is formed of *débris* masking a core of ice. Crevasses disturb the regularity of a moraine. Sometimes it is almost wholly engulfed; the disappearance, however, is to a great extent temporary—for though some blocks may even reach the bottom of the

glacier, others do not get far down, and are presently, as it were, excreted on the surface.* But after the descent of an icefall the bank-like form is generally lost; so the broken rocks, as a glacier proceeds, tend to disperse, and toward the end are scattered broadcast over the surface, sometimes so thickly as to mask the ice. At last, when it has melted away, they fall to the ground, and form a

FIG. 52.—GLACIER WITH MORAINE (MER DE GLACE).

"terminal" moraine at the foot of the glacier. If the ice for some time neither advance nor retire, the materials for a considerable period will be dropped at the same spot, and the moraines, lateral and terminal, will be large. Thus they remain when a glacier has melted away as monuments of its former extent and of the spots at which it has halted on its retreat. If no pause be made, its bed is

* Their reappearance is largely due to the melting of the ice, but it is possible that in such a position there is a sort of up-cast current in the ice itself.

strewn, pretty uniformly, with *débris*, but the materials are not at all sorted as when distributed by water, for blocks large and small lie side by side. Geologists hold different opinions as to the fate of a moraine when a glacier advances. Much of the material is probably pushed before the ice, but some may be overridden. A well-marked moraine cannot be mistaken. A bank of *débris*, sometimes several yards high,* rudely triangular in section, runs along the hillside, gently descending toward the bed of the valley, and forming, as it crosses, a curve, with the apex pointing downward. Even when the materials are scattered and the bank-like form is not retained a moraine often can be distinguished both from ordinary talus—since it consists of rocks which occur, not in the vicinity, but higher up the valley—and from torrent *débris* by the comparative rarity of water-worn fragments. Rounded or striated blocks are scarce in moraines of glaciers, such as those in the Alps, because the material which has been carried beneath the ice is small in quantity compared with that which has traveled upon it,† but where a region is almost buried beneath ice, as in Greenland, such blocks are doubtless much more abundant. A certain amount of material, large or small, makes part of its journey embedded in the ice, and will also escape unworn, but the amount of it probably depends on local circumstances, especially on the frequency of "icefalls."

Scattered blocks also occur on the surface of a glacier where a small medial moraine has been dispersed or falling rocks have come to rest after a longer leap than usual. These sometimes present a rather singular appearance, for a flattish block is supported by a pedestal of ice, the whole bearing a rough resemblance to a mushroom. The origin of a glacier table, as this is called, is simple. When a thick slab of rock is lying upon a glacier, it protects the ice beneath it from the sun, while all that around is thawing; thus a pedestal is gradually developed as the surrounding surface is lowered. But the sides of this are presently cut back by the oblique rays of the sun and by exposure to the warmer air, so that the block above overhangs its support more and more. At last, however, it slips off, and the process begins again. Solitary blocks also are dropped by a retreating glacier on the rocky slopes; occasionally they are left curiously poised on the curving hummocks. Such are called

* From ten to twenty yards is common. Occasionally the height of terminal moraines may be measured by hundreds of feet, but these are exceptional cases.

† Such bowlders should be most abundant in the lowest part of the moraine.

"perched blocks," and in many instances are among the surest criteria of the former presence of a glacier. At the opening of the Val d'Illiez huge blocks of granitic rock from the eastern part of the range of Mont Blanc lie among the vineyards or are shaded by Spanish chestnuts; similar blocks are scattered among the woods on the limestone slopes of the Jura some hundreds of feet above the Lake of Neuchâtel. These prove that, as already said (page 135), the glaciers from the Pyrenean chain once upon a time overflowed not only the sites of Vevay and of Chillon, but also the rich lowland of Vaud and the historic shores of Morat.

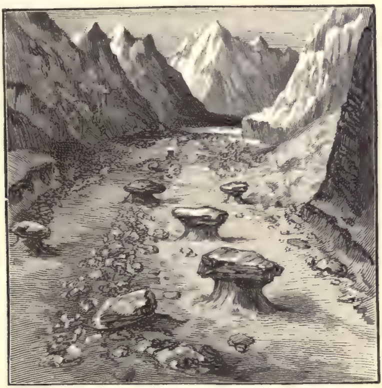


FIG. 53.—GLACIER TABLES.

Some *débris* travels between the ice and the rock, consisting of engulfed fragments and of the finer detritus produced by the rasping action of the glacier on its bed. This is designated ground moraine, or *moraine profonde*. The fact is indubitable; but its importance is more open to question. According to some geologists ground moraine may accumulate under favorable circumstances to a thickness of at least a hundred feet, and may spread like a mantle over hundreds of square miles. According to others it is a deposit generally very limited in thickness, and often amounts to no more than a film of mud or an interrupted "scatter" of stones. Beneath the glaciers of the Alps there is but little ground moraine; here and there a bowlder may be seen on its subglacial journey, the surface of rock or of ice may be smeared with mud, but the *débris*,

so far as is known, simply travels, and does not accumulate. A glacier may sometimes override its terminal moraine, disturbing, and to some extent rearranging, the materials, but there is no evidence to show that any such deposit, unless it be drawn out so as to be very thin, can be dragged far. In such a case the glacier probably would pare away the upper part of the moraine and then slide over the rest, which would remain comparatively undisturbed. This fact, at any rate, is certain—that the Alpine glaciers have retreated during the last thirty years for some hundreds of yards, and have left exposed, not beds of clay mingled with subangular

FIG. 54.—A PERCHED BLOCK.

and striated stones, but either bowlders and big pebbles, such as are transported by the torrent a little lower down the valley, or bare surfaces of ice-worn rock, sprinkled, however, occasionally with *débris* dropped from above by the receding glacier.

As a discussion of the origin of till and bowlder clay would necessarily travel beyond the proper limits of this chapter, the foregoing remarks on ground moraine may suffice for the present. It may possibly exist beneath the gigantic glaciers of Greenland, where, beyond the marginal zone of rocky hills, the ice extends inland unbroken for hundreds of miles, and a stone is seldom or never found on its surface; but neither under the Alpine glaciers, so far as can be seen, nor in the valleys for many miles below their present extremities, can any trace be discovered of a ground moraine of real

importance, so that, notwithstanding it looms so large in literature, it may be comparatively a dwarf in the realm of fact.

Still the quantity of *débris* that passes beneath a glacier, especially in the form of mud, is considerable. This is gathered together by the water from the melting ice, and is swept into the main torrent, which, when it issues from the ice cave at the end of a glacier, is always gray with suspended mud.* It has been estimated that the average amount of sediment in the water of such a torrent is about 1 in 20,000 by weight. Dr. Heim† states that the amount of detritus removed annually by all the Justedal glaciers in Norway is about equal to a cube of rock measuring 134½ feet on each side. The comparative efficiency of torrents and of glaciers as agents of denudation is still a matter of dispute. Dr. Heim, after considering estimates of the amount of mud transported in each case, is of opinion that glacier erosion is very insignificant in its effects compared with that caused by running water. It must, however, be admitted that, until the question of the real importance of ground moraine is settled, no very satisfactory basis for a comparison exists, because it cannot be determined how much of the material worn away by a glacier from the underlying rock is carried under the ice and extruded at the end, so as to be kept always separate from that conveyed by the torrent. There is also another disturbing factor, which, however, operates in the contrary direction. The glacier torrent represents more than the melting of the ice, and must convey materials in addition to those worn from the rock beneath. Streams come plunging down the hills on either side to burrow beneath the ice, and then join the main torrent. These must often transport considerable quantities of mud and stones, which represent the work both of other glaciers and of ordinary erosion. Rock *débris* falls, as already described, on to the surface of the ice, and a portion of it ultimately finds its way to the bottom, and may help to augment the contents of the torrent. Thus, at the present time, it seems hardly possible to make any very trustworthy estimates, or to do more than compare the amount transported by glacier streams (representing the total product of a certain area) with that carried by a river which drains a tract of about the same extent, and of similar configuration, entirely free from glaciers. But in the present

* The water is not only diminished in quantity, but also cleaner in the winter season.

† "Handbuch der Gletscherkunde," a work full of valuable facts and observations, of which an excellent summary (by Mr. F. F. Tuckett) is given in the *Alpine Journal*, vol. xii.

FIG. 55.—ON A GREENLAND ICE-SHEET.

writer's opinion Dr. Heim, even if he may have slightly undervalued the erosive power of glaciers, cannot be very far wrong in regarding their action as less important than that of rivers. Certainly the indirect evidence obtained from the structure of the Alps, and other mountain regions in the northern hemisphere, points distinctly toward these conclusions. Striking as the rounded contours and other marks of glacial action may be in the valleys above the lakes, and especially in their upper glens, where the ice longest

FIG. 56.—THE FORMATION OF AN ICEBERG.

lingered, yet even in such a one as the Hasli-thal, which is almost proverbial as an instance of the effects produced by glaciers, the main features of the scenery are those indicative of the ordinary work of rain and rivers. These the ice has modified; it has abraded prominences and rounded off edges; like the fickle Roman, it has changed rectangles into curves; but it has often failed to obliterate crags and terraced rocks which at no time can have been of any great size.

In the cold circumpolar regions, whether of north or of south, the huge sheets of inland ice descend to the sea in great rolling glaciers, sometimes several miles in width. Creeping along its rocky floor the ice for a time displaces the water, but is then subjected to an upward pressure, as the latter is the heavier.* This at last prevails; huge masses are broken off the end of the glacier, and after

* A cubic foot of sea water weighs about 1026 ounces, the same quantity of ice 918 ounces.

a brief period of wild flurry the newborn berg drifts out to sea. But the ship of ice does not start on its voyage without some cargo; mud and stones are frozen to its base, are embedded in its mass, perhaps are scattered on its surface. These are transported from Arctic or Antarctic regions to more genial climates. As the bergs are sometimes of immense size—often measuring in area hundreds

FIG. 57.—ICEBERGS FLOATING OUT TO SEA.

of square yards, and, occasionally, more than a hundred square miles—and their floating power is great—for, on an average, a cubic foot of rock can be just supported by a cubic yard of ice in sea water—large quantities of *débris* may be easily carried to considerable distances. This cargo is gradually discharged as the ice melts. Thousands of tons of mud and of rock fragments must be dropped every year on the Great Bank of Newfoundland; but the bergs travel much further to the south, sometimes wandering down to the latitude of Madrid (41° N.); and in the southern hemisphere, where the floating masses are often even larger than in the northern, they come nearer to the equator by three or four degrees.

But in circumpolar regions ice also forms in winter time both on the surface of the sea and on the margin of the land. The drifting snow, splashed by the spray, is frozen on the beach, and builds up

a terrace called an ice foot. This is attached to the shore, but the sea or "floe" ice rises and falls with the tide. The latter, however, may be stranded on flat coasts by gales, and is then moved up and down, wearing and striating the stones in the frozen ground, and producing on them the same effects as would result from a journey beneath a glacier.* Bowlders may be embedded in the ice foot, or masses of rock, detached by the frosts, may fall on to it from the cliffs; these, at the coming of the summer, are floated away as on a raft, to be deposited ultimately, when it either is capsized or is sunk by their weight, upon the bed of the sea.

One other method of ice transport, though less important, must be mentioned. In regions where the winters are very severe the ground may be frozen to a depth below the level of the bed of a lake or river. Thus when the temperature of the whole mass of water is low a crust of ice, adhering to stones, mud, etc., may form at the bottom as well as at the top. At the breaking up of the frost this ultimately floats, and carries off with it portions of the bottom *débris*, which, in the case of a river, may be drifted to considerable distances.

To conclude: though the action of ice, both as an agent of erosion and of transportation, has been sometimes overestimated; though it might almost as reasonably be called the maker of Tanganyika as of the Lake of Geneva, of the Black Sea as of Lake Superior; though bowlder clays, as a rule, may require for their origin something more than a glacier, and ground moraines may be greater in fancy than in fact; though the extent of ancient ice sheets may have been exaggerated; though they may have never taken complete possession of the beds of the North Sea or of the Irish Channel, or even threatened to invade the valley of the Thames; though, in a word, ice may not have accomplished all with which it has been credited in the poetry of science, still its claim to be regarded as an important factor in sculpturing and modeling the earth's crust cannot be contested even in the most sober prose.

* Feilden, *Quarterly Journal of the Geological Society*, vol. xxxiv. 1878, p. 565.

CHAPTER VI.

THE WORK OF THE OCEAN—MARRING AND MAKING.

THE sea, like the other modes of water, both destroys and transports. Its chemical action differs but little from that of fresh water; but it is less conspicuous, and perhaps, on the whole, less important, destructively. Its waters, like those of a river, must have a corrosive effect upon the rocks which are exposed to them, but the amount of this is less easily estimated than in the other case.* The quantity of mineral salts in a sample of sea water can be readily calculated, but it is less easy to ascertain how much of this has been brought down by rivers, and how much obtained by the sea itself from the rocks over which its waves are dashed and its currents flow. Doubtless it is a cause of chemical change, but this sometimes is protective rather than destructive, as when the carbonate of lime in organisms is converted by its action into dolomite,† a harder and more durable salt. Minerals also are generated, perhaps indirectly, by its action on sediments. In shallow waters iron sulphide forms so abundantly as to give a marked tint to the mud on the bottom; in the deep recesses of the ocean nodules of manganese oxide and minute crystals of various silicates are formed. At considerable depths, rather below two thousand fathoms, the sea water undoubtedly decomposes the tiny calcareous organisms with which, as will be described later on, the ocean bed is thickly strewn, for these are found, on examination, to become gradually corroded until they finally disappear. The same process must be continued as the water percolates through materials which have previously accumulated, and siliceous organisms will be also destroyed in proc-

* According to Mr. C. Parkinson (*Quarterly Journal of the Geological Society*, vol. xl. 1884, p. 254) the chemical action of salt water on metallic substances is very great. "A strong iron pipe corrodes to such an extent that the piping can be cut through with a knife like so much soap. Marble slabs gradually become pulverized by the brine, and all cements are eaten away;" but the proportion of salts in the Worcestershire brine is fully ten times as great as in sea water.

† Dolomite is a carbonate of lime and of magnesia in the proportion of 54.35 of one to 45.65 of the other.

VAAGEKALLEN—LOFOTEN ISLANDS—WORK OF WEATHER AND GLACIER.

ess of time. But it must be remembered that, though chemical change is facilitated by the presence of water, there will be hardly any transference of mineral matter unless the water actually percolates, and that under the deeper parts of the ocean it must be as nearly as possible at rest. As it is strained through rock filters, sea water parts with its mineral constituents, so that ultimately its history in traveling through the earth's crust becomes identical with that of fresh water.

The saltness of the sea is evidence of its power of transport, if not of destruction, for at least a very large part of the salt is brought down into the sea by rivers. This, however, must be uniformly distributed by diffusion or by currents, for ocean water has practically the same composition in all parts of the globe. True, it is a little more salt in warm regions than in cold, but this difference is due to the greater amount of evaporation; for a time also it is more brackish—at any rate, near the surface—in the neighborhood of the mouth of a large river. That the mineral substances must be mainly, if not wholly, brought down in solution by the rivers is proved by the fact that every sheet of water for which there is no outlet is salt. Evaporation cannot remove the solid constituents, which, as has been shown, are present in greater or less degree in every stream; so they remain behind, and the water very slowly, but very surely, becomes more salt. There was a time, as is proved by the character of the fossils which are found in beds high above the present level of the water, when the Dead Sea was but slightly brackish; it is salter now than it was when the kings of Elam came down to harry the Cities of the Plain. The ocean also may be more salt at the present time than it was when the world was young; it would become much more so if countless millions of minute organisms were not ever drawing from it the supplies which are needed in the construction of the solid parts of their bodily frames. The formation of mineral substances by the indirect action of the sea, and the consequent withdrawal of some of its constituents, proceed, as we have said, both in shallow and in deep water, but it is only under exceptional circumstances that precipitation on an important scale takes place, the usual minerals being common salt and gypsum, which are deposited in crystals, isolated masses, or beds. These, however, are more commonly the product of true inland seas, like the Dead Sea and the Great Salt Lake of Utah—as a rule, the water of the ocean is far from reaching the saturation point for any one of its constituents, or for all of them together.

It would contain, for instance, quite five times as much carbonate of lime as is ever present in its waters without being saturated. Still whatever is not withdrawn by organic or chemical action—and it is probable some constituents are not—must accumulate, so that the sea may now contain more of certain salts than in its earliest times. But there may be less of others, because no organisms then existed to draw upon its store of carbonate of lime and of silica.

The sea acts mechanically by its waves and its currents. For destruction the former are generally more important, for transportation the latter. Currents in the sea differ from rivers on the land at least in this respect. The one, like winds, move on and through a fluid of similar nature, the others run in definite channels, bounded by a different material. Accordingly the latter are more destructive than the former; a great marine current may run its whole course and do scarcely any work in abrading the bed of an ocean or the shore of a continent. Still, under certain circumstances, the erosive effects of currents, especially in shallow seas, are far from unimportant. On some coasts the currents, originated by tidal movements, though limited in duration, cannot but produce important changes. Twice daily an estuary like that of the Dee, opposite to Flint, becomes one broad sheet of water; in six hours' time it is a waste of sand, over which a few narrow and very shallow streams are wandering seaward. This mass of water, as it moves backward and forward, and especially in the later stages of its retreat, must abrade the shoals and banks and tend to sweep loose material out to sea. Still much of this, especially the finer sediments, since the water shortly moves in the contrary direction, will oscillate to and fro, as unfortunately happens with the sewage of London in the lower reaches of the Thames, so that the transference seaward will be gradual: nevertheless a transference there must be. Twice daily the sea runs like a mill race through the rocky portal which separates Brecqhou from Sark, and tidal currents hardly less rapid are generated at many places around the coasts of the Channel Islands. The cliffs and skerries, for a time at least, are scoured by a stream not less vigorous than that of a rapid river. Crags also and shores which are exposed to the full force of one of the greater ocean currents, such as the Gulf Stream, cannot but feel the effects, which, perhaps, will be most marked in the channels between islands where the sea bed comes comparatively near the surface, and is thus swept by the more quickly run-

ning water. But as the great currents for the most part strike away from land into the deeper regions of the ocean, their work is one of transport rather than of destruction, and even in doing that only the lighter materials are carried to any very great distance, while with such as float it is difficult to say to what extent they may have been drifted by the winds. Thus the sea must play no

FIG. 58.—ICE-WORN HEADLAND IN FJORD, NEAR LAURVIK, NORWAY.

unimportant part in the distribution of life, especially vegetable, by carrying unwilling colonists from land to land.

The waves are the ocean's chief weapon of destruction, the battering rams which shatter the rocky bulwarks of sea-girt continents. Their power and their work can be readily studied wherever the land falls steeply to the sea, but seldom so well as on the coast of Norway. Here the mainland is fringed by a zone of rocky islands of all sizes, from a few square yards to some miles in area, and is pierced at intervals by fjords. On the open sea the wind may be blowing a gale, the waves may be running high, but in these land-locked recesses only a faint measured throb indicates the tumultuous beating of the great ocean heart. Here, then, on every side the rounded domes of ice-worn rock slope gently down beneath the surface of the fjord (Fig. 58). But as the open water is gradually approached, the smooth surfaces begin to be scarred by rifts and gullies where the waves have found the weak places—joints, literally, in the harness of the mass (Fig. 59). The sea springs upon the obstacle, like a tiger at an elephant, and leaves the marks of its claws where the hide is most vulnerable. Further on the rifts become wider and wider, till the last remnant of ice-worn rock disappears, and ragged skerries drip with the creamy surge. If the

coast juts out beyond the island barrier, its contours are changed at once. The cliffs of Stadtlandet, which front the swell of the open Atlantic, are worn and torn and gashed from the top to the bottom, but among the islands north and south the rock descends to the water in rolling hummocks, molded by the long-vanished ice sheet.

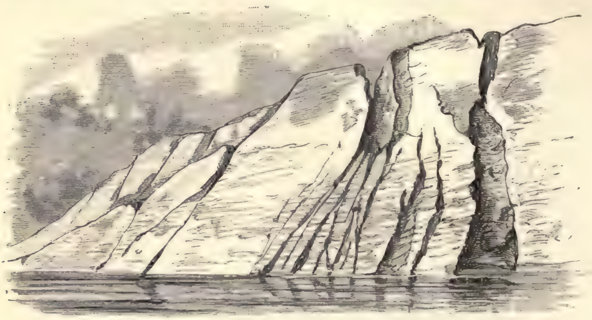


FIG. 59.—ICE-WORN ROCK TORN BY WAVES, NEAR LANGESUND, NORWAY.

The force of the waves has been measured on some exposed coasts, and an idea of their power as battering rams may be gathered from the results. At the Skerryvore lighthouse, on Tiree, the average pressure during the six winter months has been estimated at 2086 pounds on the square foot, the greatest amount recorded being 6083 pounds. Even at the Bell Rock lighthouse, in the comparatively sheltered waters off the mouth of the Tay, a pressure amounting to 3013 pounds on the square foot was registered between September, 1844, and March, 1845, and on one occasion, during a storm in the month of November, 1827, this exceeded the record at Skerryvore, for it rose up to 6720 pounds. On that occasion the spray dashed up to a height of 117 feet. But on the Island of Stroma the surge has been known to make leaps yet more gigantic, for during a storm in the month of December, 1862, seaweed, wreckage, and stones were hurled even up to the top of a cliff 200 feet in height.* On the shore huge blocks have been thrust by the waves from their resting places, or even wrenched away from the crags. Masses a couple of hundred cubic feet or more in volume have been rolled along the beach for distances of 40 or 50 yards.

* Several remarkable cases are given in Sir A. Geikie's charming volume, "The Scenery of Scotland," part i. ch. iii.

One block weighing eight tons and a half was carried full 60 feet beyond the usual margin of high water; others, in some cases even thirteen tons in weight, were torn from parts of the cliffs as much as 70 feet above the surface of the sea. Little wonder, then, if the

FIG. 60.—WAVES BREAKING ON THE BEACH.

waves, like carking care, are destroying the coast of Britain, and this

> "Little world,
> This precious stone set in the silver sea,
> Which serves it in the office of a wall,
> Or for a moat defensive to a house,"

is being corroded by its setting, and has to pay blackmail for protection.

On the rock-bound coasts the advance, though sure, is slow. The waves break for many a year on the crags of the Land's End or of the Lizard Head, of Donegal or of the Orkneys, before any appreciable change is produced; but when the cliffs consist of softer materials the work of destruction is much more rapid. In many places on the eastern coasts of England, from south of Flamborough Head to north of Yarmouth, the cliffs, often from one to two hundred feet high, are composed of nothing stronger than a tough clay, interbedded sometimes regularly, sometimes very irregularly,

with sand. Here the ruin proceeds apace. Ravenspur, where Bolingbroke landed, has been washed away; Beacon Cliff, near Dimlington, is disappearing at the rate of nearly 7 feet a year. The site of Roman Cromer lies, it is said, about 2 miles out at sea, and destruction progresses rapidly all along the coast for some miles on both sides of the town. At Sherringham there was in 1829 a depth of 20 feet (sufficient to float a frigate) at one point in the harbor of that port where only forty-eight years before a cliff 50 feet high had been standing, with houses upon it.* The graveyard of Overstrand is crumbling down to the shore; the tower of Eccles Church stands a lonely ruin on the level sand (Fig. 31). A few miles south of Cromer, in the month of April, 1892, the green lines of springing corn in the fields were cut short by the margin of the cliff, showing that, since the time of sowing, masses of land, sometimes two or three yards wide, had slipped away.

The coast of Suffolk, of Essex, and of Kent has suffered in like manner. The annals of Dunwich, since the days of Edward the Confessor, are a dismal record of destruction—monastery, town-hall, churches and churchyards, quays, streets and buildings of all kinds, neighboring fields and woods, have been swept away piecemeal; and though this place has been continually retreating inland for safety, a small village, with a single old church, represents a once flourishing town. The story of Reculver Church is not less remarkable. At this place, as at Richborough, the Romans built a fortress to guard the channel dividing Kent from the Isle of Thanet. This became the residence of Ethelbert when he gave up to Augustine his palace in Canterbury. A church was built in due course about eighty yards further inland. This, in the reign of Henry VIII., was about a mile from the sea; yet in the year 1780 the last remnants of the massive masonry of the Roman fortress fell down upon the beach. By 1804 the churchyard itself had been partly swept away. The church was considered to be no longer safe, and was dismantled; it is, however, still standing at the verge of the cliff, but it would long since have perished if the value of its two low spires as a landmark for sailors had not induced the Trinity Board to construct a sea wall, by which the advance of the waters has been arrested.

Instances might be multiplied from the eastern and southern shores of England. The Needles of the Isle of Wight, the Old

* Full details of this and several other instances will be found in Sir C. Lyell's classic work, "The Principles of Geology," ch. xx.

Harry Rocks near Swanage (Fig. 61), the Parson and Clerk at Dawlish, every wave-worn skerry on the coast is a monument of the destructive force of the ocean. From some of these parts have been washed away within the memory of living men; of others

FIG. 61.—OLD HARRY ROCKS, NEAR SWANAGE.

like losses are preserved by tradition; all are monuments of similar deeds which have no other record than in the undated annals of Nature.

The waves wreak their fury chiefly on the lower part of a cliff. A line of breakers is like a train of the battering rams of olden times at work on the wall of a castle. Its masonry is sapped at the base, and great pieces flake off from the upper part. But the wave is an assailant yet more persistent than the battering ram, for it pounds fragments into pebbles, which, perhaps, are hurled as

missiles against the very crag from which they were derived. The joints in the rock also, as stated above, give an advantage to the assailant; like rifts in a sea wall, they weaken the defenses. They are deepened and enlarged by the waves, so that in places gaping fissures scar the cliff. On part of the coast of Skye a curious effect is produced by the occurrence of rocks differing in hardness. The cliffs of the headland of Strathaird consist of a calcareous sandstone rather evenly bedded, but this has been cut again and again by

FIG. 62.—GULLEYS IN PLACE OF DYKES—STRATHAIRD, SKYE.

dykes* of basalt. These, strange to say, have yielded to the waves more readily than the sedimentary rock, with the result that the cliff has been carved into a line of bastion-like masses separated by narrow gullies. In other parts of the island the opposite effect has been produced, and the dykes stand up like walls above the more friable sedimentary rocks.

Caverns are frequently excavated by the waves. It can be proved in many cases, and is probably true in almost all, that these have had their origin in some fissure which has first given access to the assailant. Sometimes the subterranean channel of a streamlet may have been thus enlarged. Sea caves, however, seem to be of two types—one, small recesses or chambers, which penetrate only a very short distance into the cliff, and may be nearly as wide as they are

* Masses of eruptive rock which have flowed into fissures rather regular in outline, and have then become solid.

deep; the other, narrow and sometimes high fissures, which can be traced into the land for many yards. The former probably are produced at parts of the cliff where for some reason, such as the set of a current or the effect of a prevalent wind, the waves strike with somewhat exceptional force; the latter generally are more complex in their origin, and to some extent may be enlarged by strains produced by compression and expansion of the air. Supposing a fissure to be already in existence, the air within must be suddenly compressed into a comparatively narrow compass whenever a wave breaks over its mouth, and must expand as rapidly when the water falls back. By this process pieces of rock will be dislodged and the fissure gradually enlarged. Asparagus Island, in Kynance Cove, affords at certain states of the tide a striking proof of the violent disturbance of the air in a fissure of this kind. The Post Office, as the place is called, consists of a couple of slit-like orifices, a few inches broad, like rude letter boxes, on the face of a shelving cliff, down which one can scramble without difficulty. If a piece of paper be lightly held close to the mouth of one of these, it is suddenly wrenched from the hand by a strong indraught of air, is sucked into the hole, and is seen no more. It is, however, prudent to trust the ocean postage, and not to peer curiously into the hole to ascertain the fate of the missive, for in a few seconds comes an outward blast of air, accompanied by a copious jet of spray, or even of water. By climbing somewhat higher the working of this peculiar system of receipt and delivery—which resembles official impertinence as a set-off for a lost letter—is readily understood. The island just at this point is all but cleft in twain by a fissure, which opens seaward. The waves at a certain state of the tide—especially when the sea is running high—break upon the entrance of the fissure, and send a mass of water surging up it, which is dashed at last against the further end. This produces the outward discharge of air and spray. Then the water rolls back; by its sudden fall an inrush of air is produced, which sucks the paper through the hole. Very similar to this, but on a larger scale, are the "blowers," or "puffing holes," not uncommon on rocky coasts. In these the fissure extends upward from the sea level till it reaches the surface of the ground some distance inland. So when a gale is blowing from the sea, and the waves are breaking high up on the shore, the water rushes up the chasm, and jets of spray leap up like fountains from the earth. Such blowers are not unfrequent on the rocky coasts of Cornwall, of Western Ireland, and of parts of Scotland, where they are exposed to the storms of

the open ocean. The "bullers" (or boilers) of Buchan are noted instances, and, according to Sir A. Geikie, "magnificent examples occur among the Orkney and Shetland Islands, some of the more shattered rocks of these northern coasts being, as it were, honeycombed by sea tunnels, many of which open up into the middle of fields and moors." *

But these fissures are not always narrow. In some cases, where

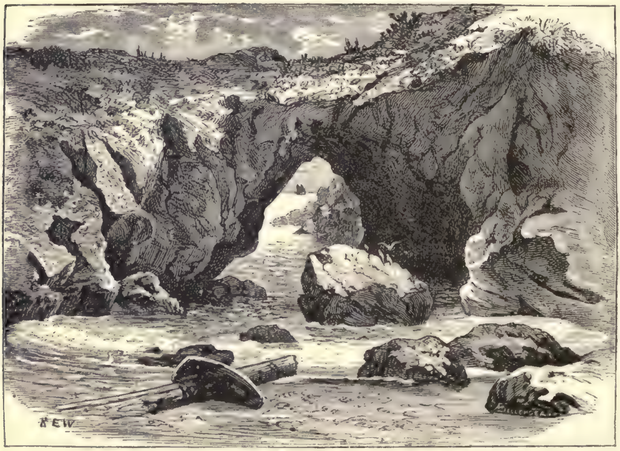


FIG. 63.—THE FRYING PAN, CADGWITH, LOOKING SEAWARD.

the structure of the rock lends itself to the work, the sides of the chasm are rapidly cut back by the force of the waves. As soon as the passage becomes a little wider than the doorway the inrushing water acquires a swirling motion, and each wave sweeps round the walls of the cavern, undermining them as it converts the corridor into a hall. As this broadens, fragments fall from its unsupported roof, and enlargement proceeds upward as well as sideward. The usual end of this process of undermining is found in the story of the Lion's Den, near the Lizard lighthouses. On the 19th of February, 1847, the greensward sloped down without a break from the crest of the hill to the edge of the cliff. Early the next morning when the light-keeper looked out toward Housel Bay he perceived that the

* "Textbook of Geology," book iii. part ii. sect. ii. § 6.

sea for a considerable distance from the point was strangely discolored. The mystery was solved as soon as he found that during the night a yawning gulf had opened out in the hillside, like a huge funnel, terminating in a rocky shaft, the bottom of which communicated with the sea by a natural archway. The roof of a cavern had suddenly fallen in, and this fearful gulf was the result. The Frying Pan at Cadgwith has doubtless had a similar history, but all record of this is lost; moreover, the pounding of the waves below and the washing of the rain above have enlarged the chasm, so that now a huge corrie-like hollow is parted from the sea only by a natural arch which is just wide enough at the top to support a narrow path (Fig. 63). The island of Sark furnishes several examples of caves converted into corridors or roofless halls. At the Gouliot caves a headland is pierced by branching passages which can be entered from the land and lead out to sea. In these at low spring tides the walls are a garden of "sea fruits," one sight of which repays a journey for many a mile. The upper parts are thickly studded with purple sea anemones, like huge carbuncles, among which are scattered some of sage-green tint and others of pale terra-cotta, which expand like the flower of a chrysanthemum. The lower parts are clothed with sponges and corallines and such like creatures, green and pink, orange and coral red, from among which sprout thousands of little balls, like white currants, pendent from a short and flexible stem; while, besides this wealth of animal life, seaweeds, brown and olive and crimson, clothe the dripping rock, and wave in the water below. The Creux Derrible, on the opposite side of the island, is a roofless hall even more astounding than the Lion's Den, for from the top of the orifice on the hillside to the bottom of the walls is an almost sheer descent of at least 150 feet, and two natural arches, separated by a massive pier, give access from the beach to an oblong hall about five-and-twenty yards wide.

Caverns such as have been mentioned sometimes bear witness to a change in the relative level of sea and land in times, geologically speaking, comparatively recent. In many places on the western coast of Scotland—as, for example, for nearly a couple of miles south of Brodick, in the Isle of Arran—a well-marked cliff runs at the base of the hills, and is separated from the present sea margin by a level rocky platform, only a very few feet above the present limit of high water. This cliff is overgrown in many places by ivy and creepers; brushwood and even trees have struck root into its crevices. Here and there at its base a recess—like a little chamber—

may be discovered; sea spleenwort and other ferns sprout from walls and roof, grass and maritime plants half hide its stony floor. But little experience is needed to recognize that cliff and cave alike are the work of the waves, and that land herbage now is growing where once the seaweeds were washing to and fro in the water. Similar proofs of wave action are to be seen here and there on the Scotch coast, and, still better, in the northern part of Norway, in the terraced banks of deltas, and in the horizontal lines furrowed by the

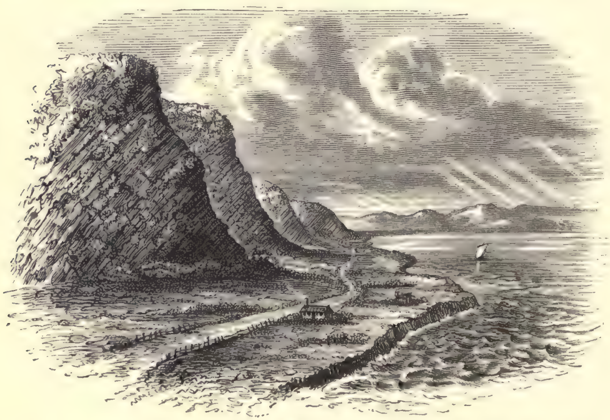


FIG. 64.—INLAND CLIFF AND OLD SEA-BED, WEST COAST OF SCOTLAND.

waves on ice-worn rocks. In the upper part of the Alten Fjord the delta deposit terminates abruptly in two well-marked lines of terraces, the crest of the higher being about 120 feet above the water.* In another place two horizontal furrows interrupt the smooth surfaces of the ice-worn bluffs, the highest being about 150 feet above sea level.

So, though the ocean must limit its destructive action to a zone comparatively narrow, and is not complementary to rain and rivers in its lines of work—for the depths of the ocean, like those of a lake, are comparatively undisturbed, and only change by the slow accumulation of fine sediment or of organic remains—it is nevertheless an engine of tremendous power within these limits, and to its

* In some places four lines of terraces are visible.

effects in modifying the features of the earth's surface, stack and archway, cliff and cavern, rocky platform and sandy wastes, once fertile fields, bear silent but unanimous witness. It may be asked, To what depth does the destructive power of the waves extend? It is, obviously, impossible to return a precise answer to this question. Much depends upon local circumstances, such as the nature of the coast, whether it overlooks a sea more or less landlocked, or is exposed to the full surge of the open ocean, and the like. It is doubtful whether the waves can have much battering power below a depth of some twenty feet from the surface, and then only in violent storms and on exposed coasts. The water, no doubt, will be disturbed to a considerably greater depth. It is said that shingle is occasionally moved off the Bill of Portland fifty feet beneath the surface, and off the Cornish coast at nearly double that depth. In the Mediterranean a heavy swell is said to be felt down to a hundred feet, and a storm produces some effect for at least fifty feet further, while at more than one locality, in rather exposed seas, sand on their bed is said to have been agitated down to the hundred-fathom line.* But though these movements may result in some slight abrasion, they are, practically, not of the slightest importance. In a vertical direction the effective zone of wave action is very limited, and probably ranges generally from about three to five fathoms beneath low water mark. Thus the waves act like a plane, and produce an almost level surface, interrupted, perhaps, here and there by an insulated mass, which, from its greater hardness, or some other accident, has escaped the general destruction. The final result of wave work is well illustrated in many parts of the British coasts, and best where the cliffs consist of rocks which are neither very hard nor very soft. Beneath the chalk cliffs on the eastern or southern coasts a rocky floor shelves gently seaward, at low tide, till it disappears beneath the water. Indeed, the great submarine plateau which extends all round the British Isles to the hundred-fathom line is, no doubt, partly a plain of marine denudation.† The surface of the land sometimes exhibits these plains, occasionally well preserved, but they even may be traced, after careful examination, in districts where rain and rivers have subsequently cut out valleys, and have almost obliterated the original structure. By many authors the hills of Cardiganshire, possibly the table-lands

* Prestwich, "Geology," vol. i. p. 118; Fol, *Geological Magazine*, 1890, p. 430.

† The result of marine denundation and of subsidence acting jointly. (See Fig. 19, page 53.)

about the Moselle and the Rhine, are regarded as the last relics of similar plains because of the general uniformity of level which is displayed by their higher parts.

The *débris* swept away from the land, or brought down to the sea by rivers, after oscillating for a time to and fro ultimately settles down to rest in deeper water. The heavier materials travel but a short distance; shingle beds, where the land has not subsided, commonly lie near to the shore, sometimes seem hardly to reach even to extreme low water mark. To what distance sand may be

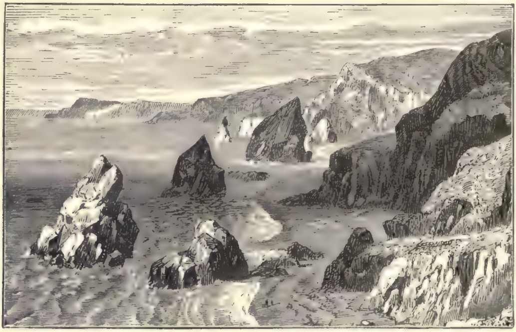


FIG. 65.—INSULATED ROCKS NEAR THE LIZARD.

carried depends greatly upon local circumstances—in rather shallow seas, where tidal or other currents are strong, it may be transported to considerable distances from land; but where the bottom falls rapidly it must soon come to rest. Probably it is generally restricted to a zone the greatest breadth of which will not exceed twenty miles.

Where the current of a river is checked at its entry into the sea deposit is rapid, and shoals are formed. This is the history of the bars commonly found at the mouths of rivers, which are often serious obstacles to navigation. At Liverpool the large ocean-going steamers can only enter or quit the Mersey during about four hours on either side of high water, for at other times the channel through the bar is too shallow. Access to the harbor of Aberdeen was actually closed after a storm in the year 1637, but fortunately the sea itself removed the obstacle after a few days. The curious pools of fresh water, parted from the sea by a bank of

shingle, which are not uncommon on the coasts of Devon and Cornwall, almost certainly owe their origin to a nearly similar cause. The sea, probably when the land stood at a slightly lower level, formed a bar across the mouth of a valley or of a little bay. This has been since upraised and enlarged, and the pool between it and the shore has gradually become fresh, for it is fed by streams from the land, and the percolation, owing to the fall of the tide, is mainly seaward.

But when a large and muddy river enters the sea the land almost

FIG. 66.—SHOALS AND CHANNELS AT THE MOUTH OF THE THAMES.

invariably advances, often rapidly. The tide may sweep the sediment backward and forward in an estuary, but the process of silting up goes on. The flow of the tide brings the water over the shallow flats; but it runs off by gravitation. During the pause a part of the suspended detritus is deposited; something is added to every shoal and dropped in every channel. The plants of the salt marsh strike root into the silt; when it has risen near to the high tide mark the muddy water is filtered by the coarse herbage, and accumulation is hastened. By degrees the soil is raised, at first by contributions from exceptionally high tides or river floods, then by gathered dust or dead vegetation, or even by the castings of worms; and so the ground grows, the mud flat becomes a salt marsh, the shoal an island, which at last is linked to the shore; the fringe of

the land is ever pushed seaward, and in this way a delta is formed, through which, commonly by more than one channel, the river flows, not unfrequently changing its principal line of discharge. The traveler from Bologna to Venice passes over more than one of these almost deserted channels of the Po, along which the water creeps, as in a canal, rather than flows. But all along the coast of Venetia the land is, and has been from time immemorial, trespassing upon the sea. Of late years it has advanced more rapidly, owing to the reckless destruction of the forests on the Italian slopes of the Alps and the careful banking of the Po itself; the one has increased the amount of *débris* swept down by the rivers, the other has prevented this from being dispersed over the plains. The average rate at which the delta advanced between the years 1200 and 1600 A. D. has been estimated at about twenty-five meters a year, but for the next two centuries at no less than seventy meters annually.* Ravenna in the reign of Augustus was traversed by canals like Venice, and was made the principal station of the Adriatic fleet. A new harbor was constructed at Classis, nearly three miles to the southeast, and the two places were united by a continuous suburb called Cæsarea. Gradually the channels leading to the quays of Ravenna and the basins of Classis were silted up, but so late as the middle of the sixth century a noble basilica was erected at the latter place.† Now the seacoast is nearly six miles from Ravenna; Cæsarea has been swept away; of the shops and counting houses of Classis nothing remains, except that its church still rises in solitary grandeur on the wide monotonous plain; a fever-stricken fen has replaced a once busy seaport. Away to the east, along the Adriatic shore, La Pineta, the "evergreen forest, which Boccaccio's lore and Dryden's lay made haunted ground" to Byron, extends almost without a break for nearly five-and-twenty miles. Some have thought that the "Adrian wave flowed o'er" the site of this "immemorial wood" when Classis was a port, but it is mentioned as far back as the days of Theodoric. The alluvial soil has accumulated to a depth of full three yards about the base of the monument to this king of the Ostrogoths, which stands in the open country about a quarter of a mile away from the wall of Ravenna. More probably the low bank of sand on which the pines are rooted formed, in classic times, a chain of islands like that

* Lyell, "Principles of Geology," ch. xviii.

† S. Apollinare in Classe, built A. D. 534–549.

which still shelters Venice from the storms of the Adriatic. But the lagoons have been filled up, and La Pineta is now part of the mainland. In some places along this coast the advance has been yet more rapid. Adria, once a seaport of some consideration, is now sixteen or seventeen miles inland. This place, however, is situated near the center of the delta, where it has already passed beyond the line of outer islands still marked by a chain of dunes, and projects several miles into the Adriatic. Yet, even in historical times, the land appears to have been slowly sinking. Venice is said to have subsided six feet* since its earliest buildings were erected, but these only go back about a thousand years, and the oldest settlement on the Venetian islets is hardly earlier than the middle of the fifth century of our era. The weight of the buildings may have squeezed the muddy soil into a smaller compass, and account in part for the subsidence; but there has been also a general sinking of the land, for an artesian well at Venice, which some years since was bored to a depth of 572 feet, passed through a series of terrestrial marshy deposits, in which here and there a band containing sea shells was intercalated.

The delta of the Rhone has also been advancing rapidly. Mèze, now on the border of an inland sheet of water, and about half a dozen miles from the actual seashore, was an island some eighteen centuries since. Notre-Dame-des-Ports, now two leagues inland, was a harbor at the end of the ninth century. Sir C. Lyell argues for the probability that some twenty centuries since, when Southern Gaul was conquered by Rome, the delta, even to the north of Arles, was not generally habitable, for the Roman road from Beaucaire to Beziers bends northward by Nismes, instead of following a straight course as usual, and the names of all the places south of it are of Latin origin, while those on the other side are frequently Celtic.

The Mississippi delta extends far out into the Gulf of Mexico. Its channel is defined by "two narrow banks of alluvium, one side of which is seashore and the other river bank. . . Projecting from the continent like an arm, it pushes out for sixty-two miles into the sea, and spreads over the water the branches of its delta, like the fingers of a gigantic hand. A Hindoo might well compare the extension of the mouths of a river to an immense flower opening over the ocean its serrated corolla." * This, however, only accounts

* Réclus, "The Earth," ch. liii. † Réclus, "The Earth," ch. liii

for a part of the vast mass of alluvium brought down by the Mississippi; large quantities are deposited on the inland surface of the wide river plain, and up to a date comparatively recent, before the floods were restricted by embankments,* a very great proportion must have been so distributed. In Lower Egypt, where the Nile flood is too welcome to the husbandman to be thus restricted, the

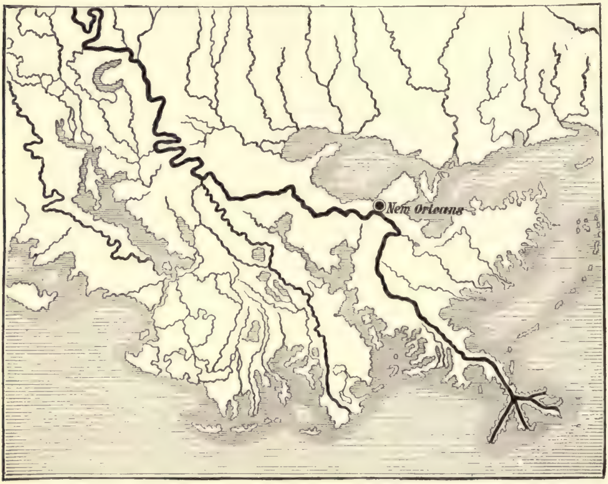


FIG. 67.—THE MISSISSIPPI DELTA.

thickness of the alluvial soil is slowly but surely increased. Mr. Horner ascertained that the Nile mud at Memphis had gathered about the base of a statue of Rameses to a depth of nine feet four inches. As the monument had been standing for about 3200 years, the rate of accumulation would be 3½ inches in a century.† The delta projects into the Mediterranean in a curve,

* The total length of these is said to amount to some two thousand miles.

† If a fragment of burnt brick was really found at the bottom of a shaft sunk sixteen feet below the base of the pedestal, the first occupation of this Nile valley by a comparatively civilized race must be carried back to a very remote period, perhaps thirteen thousand years ago. But be this as it may, borings made a few years since at Tantah and Kasr-el Nil were carried down through river mud and sand, and were discontinued at the former place at a depth of eighty-four feet without penetrating through the delta deposit, so that this about Cairo must be no small thickness.

roughly in the shape of a half ellipse, but its advance here is less rapid than might have been expected, because a rather strong current sweeps the coast, and carries away the mud to scatter it over the bed of the Mediterranean, which about here deepens rather rapidly.

This story might be repeated of every river, small or great, as it approaches the sea. In the earlier stages of its history it tends to lower its bed and the whole area which it drains; in the later it gradually changes its ways, and proceeds to build both upward and onward. Nothwithstanding the occasional opposition of coast

FIG. 68.—BIRD'S-EYE VIEW OF THE NILE DELTA, LOOKING SOUTHWARD.

currents, nothwithstanding the frequent subsidence of the delta, a fact of which some notice must be taken in a later chapter, the process of building into the sea steadily proceeds. The waves fret the coasts, the ocean devours the land, the rivers themselves " draw down Æonian hills," but then they " sow the dust of continents to be." Here the sea makes inroads, there the coast line is pushed outward. The forces of the land and the ocean are in eternal conflict on the frontier of their territories. As in the wars of nations, the result depends much on the strength of the forces brought into the field. The sea triumphs over islands, and ultimately lays low the ramparts of rock-bound coasts; but when the great rivers come down in their strength from mountain ranges, as the barbarian hordes descended upon the Italian lowlands in the days of the decline of Rome, they invade the invader, and in their turn conquer the conqueror.

CHAPTER VII.

THE PROLETARIAT OF NATURE.

THE dawn of life upon the earth introduced a new set of disturbances, initiated a fresh series of changes. All the chemistry of Nature, all the relationships of the physical forces, were affected. The drama of the earth's history became at once more complicated. The intricacies increase with the development of will and the enlarging powers of voluntary action. Thus in the present chapter it would only lead to confusion if any very rigid separation were attempted between the chemical and mechanical action of vital forces, between the destructive, conservative, and reproductive work of living creatures, or even between their direct and their indirect results. In all parts of the realm of Nature cause and effect are so united, one change so inevitably leads up to another, that it is hard to say where the chain of consequences ends when once its first link has been wrought. The results of organic action, whether destructive or reproductive, if on a scale somewhat smaller, and in modes rather less conspicuous, than those of the physical forces, are, nevertheless, of the highest importance, and to none more than to man himself. The destructive effect of plants and animals, so far as may be, shall be noticed first. Mosses, lichens, and various other plants, by direct and indirect action, corrode the surface of rocks; the roots of trees creep into crevices, and in growing force them apart; the stem of the clinging ivy in Europe, the root of the wild fig in India, becomes a living wedge to rend the masonry into the joints of which it has gained access. Animals also there are which can honeycomb the surface of rock. The sea urchin on the Biscayan coast rests within a saucer-like depression, which it has excavated for itself; mollusks such as the *Pholas, Modiola*, and *Saxicava* dig deep into rock, some of them pierce the branches of corals, which then are more easily snapped off by the waves; even the limpet by long persistence at the same spot impresses the print of his disk-like foot on the hard surface. Floating wood and piles are mined by the teredo and other foes. On the dry land several species of

snail pierce into limestone, to a depth sometimes of three or four inches. Many animals are habitual burrowers. Throwing up the soil facilitates its removal by wind and rain, but by the breaking up of the surface and the transference of material vegetable growth is made more easy. The common earthworm, as the late C. Darwin proved in his book entitled "The Formation of Vegetable Mold Through the Action of Worms," plays a most important part in the transference of material. "In the eyes of most men," to quote the words of a reviewer, "the earthworm is a mere blind, dumb, senseless, and unpleasantly slimy annelid. Mr. Darwin undertakes to rehabilitate his character, and the earthworm steps forth at once as an intelligent and beneficent personage, a worker of vast geological changes, a planer down of mountain sides—a friend of man." * Similar work is performed by several other animals, but it is not always so beneficent. The mole makes his tunnel and heaps up the castings; mice, rats, rabbits, prairie dogs, gophers, and other rodents carry on their work of burrowing in the parts of the globe which they severally inhabit. By this the surface of the ground is loosened, fresh material is exposed to the action of wind and weather, and other matter is buried out of sight. "The embankments of the Mississippi are sometimes weakened to such an extent by the burrowings of the crayfish as to give way and allow the river to inundate the surrounding country. Similar results have happened in Europe from the subterranean operations of rats."† The constructive habits of the beaver also locally derange the economy of the globe, for its dams arrest the flow of streams and convert shallow valleys into pools and morasses. It must not be forgotten that the one word "food" connotes a long series of destructive changes, not less important indirectly than directly. If a drowned sheep lies rotting in the mud of a marsh, it initiates one series of changes; if it has disappeared down the throat of an alligator, it starts another—the results in the two cases being very different.

But the protective action of plants is also very great. The growing herb is like an armor-plate to defend the soil against the missiles of the sky; the force of the rain is broken by the leaves, the loose earth is bound together by the roots, and by both the flow of running water is checked. The Brenner railway, where it runs along the mountain side, is partly supported by embankments. In August, 1867, when it was opened for traffic, the surface of these

* "Life and Letters of C. Darwin," vol. iii. ch. vi.

† See Sir A. Geikie, "Textbook of Geology," book iii. part ii. sect. iii. § 1.

banks consisted of stony earth, freshly upturned. Immense trouble had been taken by the engineers to protect them from the action of the mountain storms; stakes had been driven into the earth, and long sticks twisted between them so as to form little fences about six inches high, and cover the bank with a diagonal network of wattles, and in the interspaces—a few feet in diameter—shrubs had been roughly planted or grass had been sown. By the summer of 1872 the slopes generally were covered with vegetation, the fences were rotting away and were often overgrown, and the banks were obviously safe; but here and there, owing to some exceptional circumstances, the rain had gained a temporary victory—the fences had been destroyed, the soil washed away—and fresh earth and new wattles showed that this struggle was continued. The mountain side is similarly protected by its panoply of herbage, brushwood, and forest; and where there is much grass on steppe or prairie, there dust storms are impossible. Were it not for the restraining effect of the marram grass and other plants the sand dunes would often advance much further inland, and convert miles of fertile country into desolate wastes. Even beneath the sea plant life must have some conservative effects. The waving forests of seaweed cannot but check the force of waves and currents, and shield the banks and crags from the rush of water. Much is done, as by the forests on the land, when calcareous algæ, serpulæ, corallines, barnacles, and other organisms cover, as with a coat of roughcast plaster, the surface of the rock, which cannot be abraded while the brunt of the storm is borne by this living cuticle. It exacts, doubtless, wage for its work. Every organism is a secret and never idle laboratory of chemistry, the products of which initiate endless changes, but the extent of these is difficult to detect and almost impossible to estimate. From decaying plants come various acids—among them humic and uric—which combine readily with oxygen, and so facilitate the formation of metallic sulphides and even of native metals. The pyrite (or iron sulphide), which gives a dark tint to many of the shallow water marine muds, which spangles or burnishes fossils, which glitters in the lumps of coal, which occurs in bright nodules in chalk or other rocks, indirectly owes its presence to the action of these organic acids. Nodular masses—called concretions, or septarian stones—are commonly found in clays and shales, and sometimes in other sedimentary rocks. When one of these is broken open it usually discloses as its nucleus some organism—it may be a leaf of a plant, a shell, or perchance a bone. This

has begun the deposition of a mineral—such as silica, phosphate or carbonate of lime, or carbonate of iron—which has cemented the softer materials of the rock into a hard, solid lump. In this, sometimes, cracks, subsequently formed, have been filled up.

The effect which the decomposition of an organism can produce in initiating mineral changes may be illustrated by two examples—the one simple, the other more complex. For the former it is only needful to search in any district where the surface consists of a fawn-colored sand, such as that of the Bagshot heaths. Where the dead roots of trees are exposed in an excavation the sand around them is commonly found to be bleached for a distance of an inch or so. The tint of the sand is caused by the presence of limonite (iron rust). The decaying wood has produced an acid which has attacked the limonite, and formed a salt of iron readily soluble in water, which has then been removed, leaving the sand colorless, as though it had been washed in hydrochloric acid or some other bleaching fluid. The other instance was described many years since in the "Transactions of the Geological Society."* "An earthen pitcher, containing several quarts of sulphate of iron, had remained undisturbed and unnoticed for about a twelvemonth in the laboratory. At the end of this time, when the liquor was examined, an oily appearance was observed on the surface, and a yellowish powder, which proved to be sulphur, together with a quantity of small hairs. At the bottom were discovered the bones of several mice in a sediment consisting of small grains of pyrites, others of sulphur, others of crystallized green sulphate of iron, and a black, muddy oxide of iron. It was evident that some mice had accidentally been drowned in the fluid, and by the mutual action of the animal matter and the sulphate of iron on each other the metallic sulphate had been deprived of its oxygen; hence the pyrites and the other compounds were thrown down."

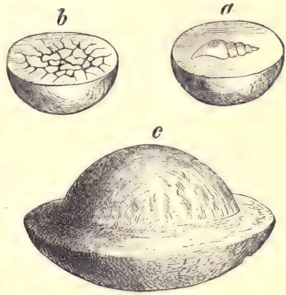


FIG. 69.—CONCRETIONS.

(*a*) With the cast of a shell in the interior; (*b*) with septaria, or cracks filled with calcareous matter; (*c*) concretion of carbonate of iron from the coal-shales of Steierdorf, Croatia.

* By Mr. Pepys, "Transactions of the Geological Society," ser. i. vol. i. p. 399—quoted by Sir C. Lyell, "Elements of Geology," ch. iv.

But the effects of life are most obvious when it acts as a constructive force. Myriads of organisms are silently at work in building up masses of rock and adding new material to the earth's crust. Most of these are simple in structure, and occupy a comparatively humble place in a biological classification, but in the realm of Nature the "task of the least" is ever the most important; to her "children of Gibeon" she looks for the work which endures. By them carbon is extracted from carbonic acids; mineral substances are withdrawn from the soil and from water. Upon this task plants and animals alike are engaged; into their structures these mineral substances are incorporated, and with them, when the work of life is ended, rock masses, often hundreds of feet in thickness, are partly or even wholly constructed.

To consider first the work of plants. Bitumen, asphalt, petroleum, and other mineral oils, which are now of such high commercial value, have been produced, in many cases at least, by the decomposition of forests of seaweed, which can hardly have been less abundant in past geological ages than at the present time. Other plants may have sometimes brought about the same result. Tiny diatoms, the delight of the microscopist, have formed, by the slow accumulation of their siliceous cases, beds of "tripoli," or "polishing earth," which of recent years has been pressed into the manufacture of dynamite. Certain algæ of extremely low organization abstract from water important quantities of carbonate of lime. Some, such as the nullipores, form branching masses like small corals. These in certain seas accumulate in considerable quantities. On the coast of Norway, for example, they abound among the rocks, and gleam white on the bed of the sea in shallow water. Of late years it has been shown that algæ also play a very important though less direct part in the formation of siliceous matter about geyser basins, and of the calcareous travertine deposited in large masses by certain springs and rivers. It matters little whether the water be hot or cold, for it has been found that some of these plants live in water which has a temperature as high as 200° F., and they begin to flourish at one which is somewhat lower.* Plant remains may sometimes accumulate in sufficient quantity to form very considerable masses; but for this favorable circumstances are required. The vegetable *débris* in an old forest

*This subject is discussed in a very elaborate report by Mr. W. H. Weed, printed in the Ninth Annual Report of the United States Geological Survey.

does not as a rule exceed a few feet in thickness. The carbonaceous and bituminous substances produced by the decomposition of plants are constituents of many rocks, but accumulation on any important scale appears to be restricted to swampy districts. On sandy ground it is often remarkable how slight an effect has been produced. Parts of the moorland of Cannock Chase, in Staffordshire, consist of a rather porous gravel; they have never been under cultivation, and, in all probability, have been above sea level for myriads of years. Here countless generations of wild plants have flourished in succession. As the surface is covered at the present day with heath and ling, with fern and gorse, with grass and other wild herbs, so it has been for long ages; yet the earth commonly is discolored only for a depth of a few inches. Trees may have once covered the ground; oaks, birches, and thorns are still scattered here and there on the slopes, but of those which died a few centuries ago no trace is left. The case, however, is different where water can stagnate. Then, in temperate or subarctic climates, peat mosses are formed. Such may be seen in the flat lowlands of Eastern England, though their area has been greatly reduced by the drainage of the fens. They are commoner in the colder and more humid climate of Scotland, they are so abundant as to be proverbial in Ireland, and are plentiful in corresponding situations on the continent of Europe. The upper part of the bog consists of growing mosses, such as *Sphagnum*, *Hypnum*, and *Bryum*, sometimes it even supports heath and moorland plants tolerant of moisture; below it is a mass of dead vegetables, becoming in the lower part brown or even black in color and compact in structure. This deposit may accumulate to a depth of at least several feet, and cover many miles of country—the Bog of Allen in Ireland, is about 238,500 acres, with an average depth of 25 feet, and it is estimated that about one-seventh of that island is occupied by peat. When one of these bogs is cut away for fuel a layer, composed largely of fresh-water shells, is sometimes found beneath, showing that the morass occupies the site of a pool, or very commonly the roots of dead trees are laid bare in such a quantity as to indicate that it originated in an old forest. Sir A. Geikie * mentions an interesting case, which proves not only this, but also that the peat grows with comparative rapidity. "In the year 1651 an ancient pine forest occupied a level tract of land

* "Textbook of Geology," book iii. part ii. sect. iii. § 3.

among the hills in the west of Ross-shire. The trees were all dead, and in a condition to be blown down by the wind. About fifteen years later every vestige of a tree had disappeared, the site being occupied by a spongy green bog, into which a man would sink up to the armpits. Before the year 1699 it had become firm enough to yield good peat for fuel." Other evidence is adduced, proving that under favorable circumstances peat increases in thickness, on a very rough average, at the rate of at least an inch a year.

Important deposits of vegetable matter are also formed by plants other than mosses. "Among the Alps, as also in the northern parts of South America, and among the Chatham Islands, east of New Zealand, various phanerogamous plants form on the surface a thick stratum of peat." * On tropical coasts the mangrove swamps, dense thickets of tangled vegetation and matted roots descending into the water, fringe the shores even down to low tide mark, and run far up into the inlets. They form a belt on the Florida coast sometimes as much as twenty miles in breadth. This must often be one vast bed of vegetable matter, living and dead. The great Dismal Swamp, in Virginia and North Carolina, is some forty miles long from north to south, and twenty-five wide, and is described by Sir C. Lyell as having "somewhat the appearance of an inundated river plain covered with aquatic trees and shrubs, the soil being as black as that of a peat bog. In its center it rises twelve feet above the flat region which bounds it. The soil, to the depth of fifteen feet, is formed of vegetable matter without any admixture of earthy particles. . . The surface of the bog is carpeted with mosses, and densely covered with ferns and reeds, above which many evergreen shrubs and trees flourish, especially the white cedar (*Cupressus thyoides*), which stands firmly supported by its long tap roots in the softest parts of the quagmire. Over the whole the deciduous cypress (*Taxodium distichum*) is seen to tower with its spreading top, in full leaf in the season when the sun's rays are hottest, and when, if not intercepted by a screen of foliage, they might soon cause the fallen leaves and dead plants of the preceding autumn to decompose, instead of adding their contributions to the peaty mass. On the surface of the whole morass lie innumerable trunks of large and tall trees blown down by the winds, while thousands of others are buried at various depths in the black mire below." † This gentle

* Sir A. Geikie, *loc. cit.*

† "Principles of Geology," ch. xliv.

rise toward the central part of the swamp is a common feature in peat bogs, as may often be noticed in Ireland. Occasionally, after unusually heavy rain, the mass swells up like a sponge, but as the result of this, owing to its less coherent nature, the bog may burst and discharge a flood of viscid black ooze over the surrounding country. The treacherous surface of the morass frequently proves fatal to animals, which are mired and engulfed, and the antiseptic properties of the material are exceptionally favorable to the preservation of their remains, as well as of the timber which it has covered up. Of this the bog oak, so often used in Ireland for ornamental purposes, is a well-known instance. Other chemical processes are set up by these changes in dead vegetable matter, leading to the formation of iron sulphides and carbonates. The former in process of time may be decomposed and produce limonite; * in short, many beds of iron ore of great commercial value are, directly or indirectly, due to the action of plant life.

Lignite and all the varieties of coal are simply great masses of vegetable material which, in the lapse of ages, have undergone chemical changes the earlier stages of which are represented by peat. They have been buried beneath hundreds, sometimes thousands, of feet of rock, and so subjected to great pressure, as well as to a somewhat higher temperature. They have been kept moist, but at the same time the air has been almost wholly excluded. By this treatment the mass has parted with a very large part of the oxygen and hydrogen originally present, so that in anthracite, which may be regarded as the last stage of the ordinary processes, carbon forms more than nine-tenths of the whole.

But a piece of ordinary coal, if studied under the microscope, is seen to consist of the remains of extinct plants, which are sometimes sufficiently well preserved to be recognized by the botanist. The coal raised in England, and most of that which is at present worked in other parts of the world, consists of the remains of plants of low organization, such as the ferns, horsetails (*Equisetum*), and club-mosses (*Lycopodium*) of the present day. The representatives of the second † and third ‡ of these in the vast morasses of the Carboniferous period attained to a size which now would be deemed gigantic, and took the place at present occupied by forest trees. §

* The hydrous peroxide of iron, identical with the common "rust" of the metal.

† The extinct *Calamites*.

‡ Especially the extinct genera *Lepidodendron* and *Sigillaria*.

§ The remains of conifers are occasionally recognized, and these, very probably, were

It has been also found that the spores of plants allied to club-mosses occasionally make up a considerable part of a seam of coal, but they are by no means always present, and are less important constituents of fuel than has been sometimes supposed.*

But from a very early epoch in the earth's history a more important part has been played in the formation of rock masses by animal than by vegetable life. One effect, which is often quite as much indirect as direct, the result of which has a scientific and a commercial interest disproportionate to its bulk, is the formation of certain deposits rich in phosphate of lime. Beds of guano are produced by the accumulated excreta of sea birds; phosphate of lime is also the chief constituent in the bones of vertebrate animals, and enters largely into the composition of the solid parts of some invertebrates, especially the crustacea; by it, accordingly, these and other organisms are sometimes mineralized, and the mud in their vicinity is impregnated and formed into nodules by a process of concentration, which occurs in Nature with many other mineral substances. This is the origin of the so-called "coprolite beds," which of late years have been largely worked for artificial manures.†

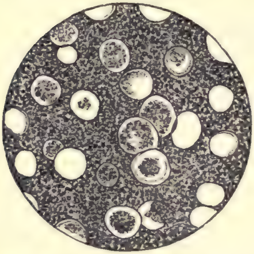


FIG. 70.—THIN SLICE OF SHALE FROM KETTLE POINT, LAKE HURON.

(Greatly magnified.) Showing the little globular spore-cases scattered through it.

At the present day, as in the past, foraminifera rank among the most important contributors to the production of marine limestone. They are commonly found mingled with the broken shells and its other constituents, and even in the case where the rock is composed of masses of coral, as will be presently described, they may help in filling up the intervals between the more branching forms.

more abundant in the upland districts, but it is unlikely that the dicotyledons, to which sub-class most of the living forest trees, especially in temperate climates, belong, were in existence at this period.

* Cannel coal, a very inflammable variety, which burns with a bright flame, often in sudden jets, and does not soil the fingers when it is handled, is supposed to have been a kind of vegetable mud, produced by the maceration of leaves, etc., in ponds.

† The name is a misnomer, for the fossils are not, as a rule, the petrified excreta of animals. The most important deposits are in the Lower Greensand of Bedfordshire and Cambridgeshire, at the base of the chalk in the Cambridgeshire district, and in the Pliocene strata of the eastern counties.

But rocks like these, which are formed in comparatively shallow waters, are composed chiefly of larger organisms; and as the sea bed deepens, the work of the foraminifera becomes more and more important. Generally they are very minute; a large number of species, including some of the most abundant, do not attain the size of an ordinary pin's head, though occasionally one of the more disk-like forms is rather broader than a threepenny piece. Such a one, however, must be regarded as a giant, though in a past epoch of

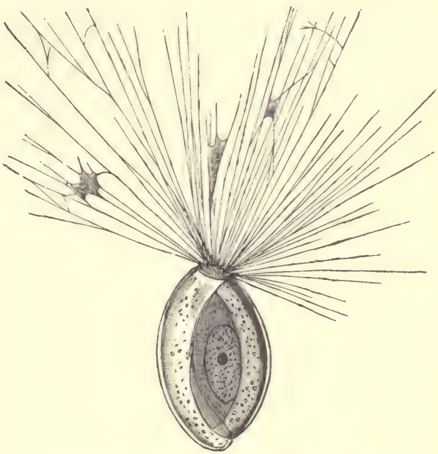


FIG. 71.—A LIVING FORAMINIFER (*Miliola*).

geology foraminifera have existed which were even larger than a florin, and occasionally at least three or four times as thick toward the middle. These creatures build up chambered structures sometimes of singular beauty and complexity, composed, in a large number of cases, of carbonate of lime, with which they are able to furnish themselves from the sea water, yet the structure of their bodies is singular in its simplicity—"sans eyes, sans teeth, sans [almost literally] everything." They are little more than tiny lumps of animated jelly, unprovided with a skin outside or a stomach inside—the only interruption to their uniformity being one or two minute hollows filled with an oil-like fluid, and one part, called the nucleus, which is rather more solid than the rest. One of these foraminifera, which plays a most important part in rock building,

bears the name *Globigerina*. Its calcareous shell is formed of chambers, about nine in number, globular or slightly oval in form, with a hole at one end. The oldest of these is the smallest, and from this they go on increasing in size, being arranged on a spiral curve, with their apertures turned inward, so as to open into a central hollow. The wall of each chamber is pierced by a number of perforations, and the outer apertures are, as it were, fenced one from another by low walls of shelly material, from the common angles of

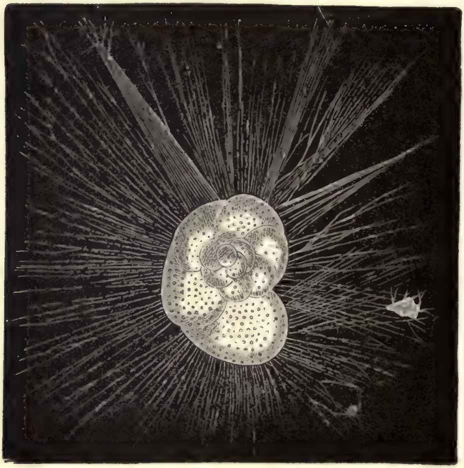


FIG. 72.—A LIVING CHAMBERED FORAMINIFER (*Pulvinulina*).

which long and delicate spines project. From these holes portions of the animal protrude as trailing threads of living jelly (Fig. 72). Yet notwithstanding such an elaborate structure—and even this is simple compared with that of some foraminifera—the shell of globigerina (not reckoning the spines, which are generally broken off) is so small that it would take almost thirty of them, placed end to end, to make up an inch. In the warmer seas the ocean water is often almost alive with these and other tiny organisms, all of them humble in structure, but not in every case calcareous. Among those composed of this material extremely minute lime-secreting algæ are very abundant—little balls invisible to the naked eye, the solid parts of which may be compared in one case to a shirt stud

(Fig. 74), in another to a kind of club, the little disks in the former being one twenty-five hundredth of an inch in length. Among the siliceous organisms are diatoms, already mentioned, and tiny animals, somewhat resembling the foraminifera, with "skeletons" rather less complicated, but, if possible, even more beautiful.

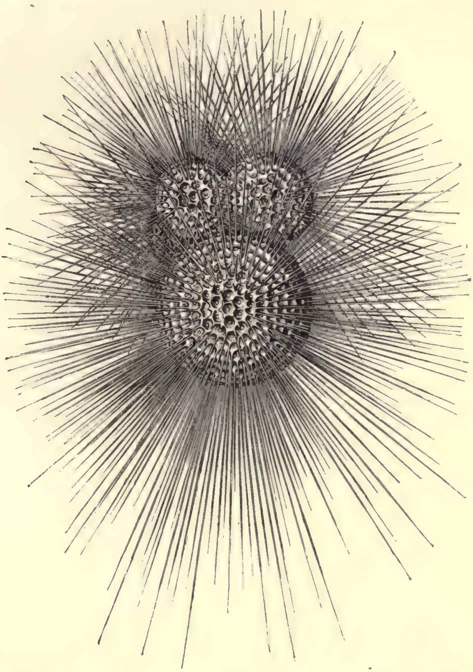


FIG. 73.—THE SHELL OF A GLOBIGERINA.

These are called *Radiolaria*. Some sponges also secrete considerable quantities of silica in the form of spicules (Fig. 76), of which the exquisitely beautiful Venus' flower basket * is a notable example. In others the spicules are calcareous, and in a third group, such as the ordinary bath sponges, they consist of a horny substance. Sponges, however, usually grow on the sea bed, and are only acci-

* *Euplectella speciosa.*

dentally found floating; but many of the foraminifera, especially globigerina, are tenants of the upper waters of the ocean, and it is doubtful whether they live at depths exceeding about five hundred fathoms. The radiolaria have been found alive at far greater depths, and it is now generally supposed that they occupy two zones in the ocean water—one at the top, like to, but possibly even deeper than, that tenanted by the foraminifera, the other extending upward for some distance from the bed of the ocean, though whether this zone invariably exists perhaps may be open to question. Thus if anyone could walk on the ocean floor, say at the depth of a thousand fathoms, myriads of organisms, chiefly globigerina, would be floating, like a living cloud, three thousand feet above his head, and this cloud would extend upward for the same distance—that is, to the very surface of the water. But the foraminifera are subject to the universal law no less than the highest of organized beings: if "every moment dies a man," in the same brief time perish hosts of globigerina. One part of their task ended, another begins. Slowly, very slowly, they drop downward through the still waters. A never-ceasing rain of its dead shells, light as the dust which drops unfelt from the atmosphere, patters down silently and incessantly on the ocean floor. Below the limits of shore deposits—whether these consist chiefly of the larger organisms, or be simple rock detritus—the bed of the sea, down to a great depth, is covered with a gray ooze, which proves on examination to be largely composed of the shells of globigerina.* So it often continues down to about 2000 fathoms, but on passing beyond this limit a change may be noticed in the appearance of the foraminifera. At first they show signs of corrosion. Then they begin to look decomposed—a yellow tinge comes over the gray, and this turns gradually, as the

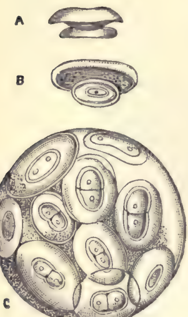


FIG. 74.—(*a*, *b*) COCCOLITHS; (*c*) COCCOSPHERES. (Greatly magnified.)

* "Under the microscope the surface layer (at a depth of 2435 fathoms in the Bay of Biscay) was found to consist chiefly of entire shells of *Globigerina bulloides*, large and small, and fragments of such shells, mixed with a quantity of amorphous calcareous matter in fine particles, a little fine sand, and many spicules, portions of spicules, and shells of radiolaria, a few spicules of sponges, and a few frustules of diatoms."—C. W. Thomson, "The Depths of the Sea," ch. ix.

depth increases, to a red. Somewhat below 2500 fathoms the character of the deposit is completely altered: the foraminifera have disappeared, and with them the calcareous elements, so that at a depth of about 3000 fathoms it is a kind of red clay. Only siliceous organisms, such as radiolaria, now remain, which in some parts of the Pacific Ocean are sufficiently abundant to give a marked

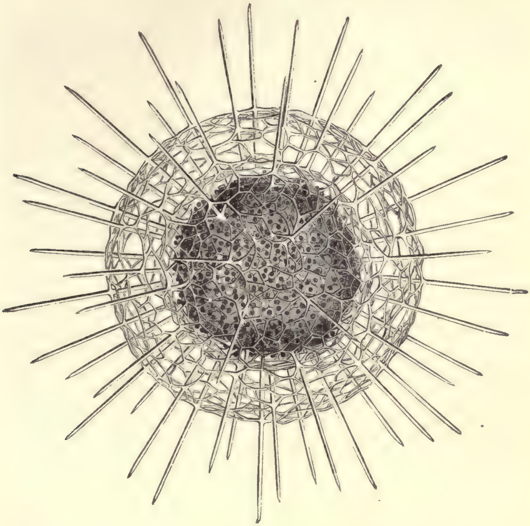


FIG. 75.—A RADIOLARIAN (*Haliomma*).
(Magnified 200 diameters.)

character to the deposit. This red clay extends downward to the greatest known depths. Even here, some 27,000 feet below the surface, the sea bed is not wholly without life. With the red clay the tubes of an annelid have been dredged up;* the existence of an abyssal fauna is a fact, though its members are not numerous either in species, genera, or individuals. The "red clay" also contains nodules of manganese oxide, which commonly have as their nucleus a shark's tooth, a bone, or even a bit of pumice; and through-

* At a depth of about eighteen thousand feet in the Atlantic, approaching Sombrero.—C. W. Thomson, "Voyage of the *Challenger*," ch. iii.

out all the deep-sea deposits small fragments of minerals and of volcanic rocks with particles referred to terrestrial and meteoric dust are found.

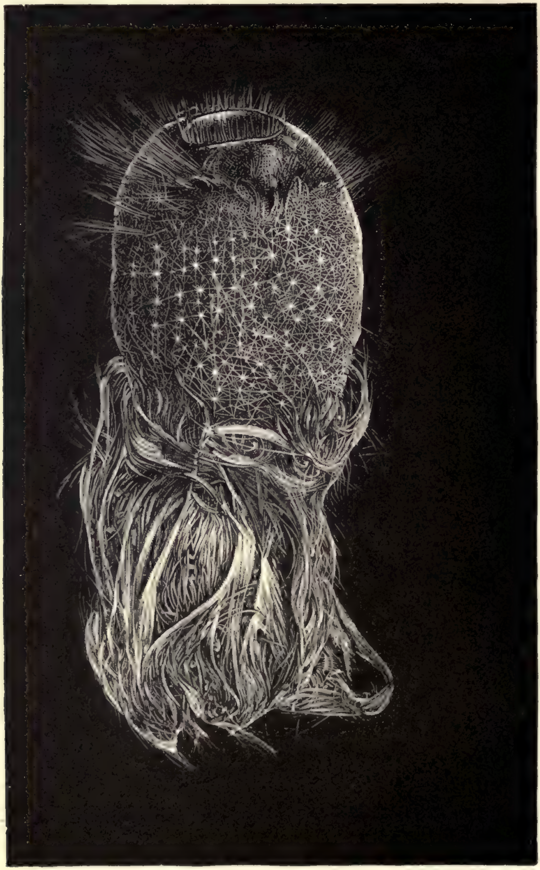


FIG. 76.—HOLTENIA CARPENTERI.
(Half natural size.) A siliceous sponge in the position of growth.

In some parts of the ocean bed—as, for instance, in the Agulhas Bank, south of the Cape of Good Hope—the tests of the dead

foraminifera are occupied by more than one variety of a hydrous silicate. The commonest is glauconite, a mineral of a strong green color, which has for its bases chiefly iron and alumina, with some soda and potash. The casts thus taken are often extraordinarily perfect, even the forms of minute tubules being preserved. Sometimes glauconite alone remains, the shell having perished. Many, if not all, of the roundish green grains so common in certain sedimentary rocks, especially in the so-called Greensand, have had this history. The origin of the red clay has given rise to much differ-

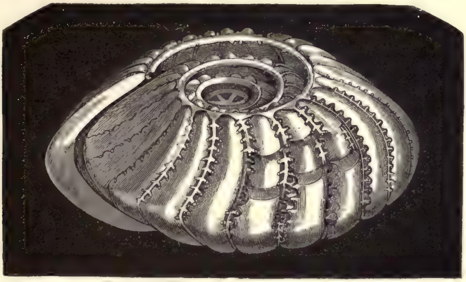


FIG. 77.—GLAUCONITIC CAST OF A CHAMBERED FORAMINIFER, SHOWING THE PASSAGES BETWEEN THE CHAMBERS.

ence of opinion, and the question cannot be regarded as finally settled. This material was at first supposed to be the almost impalpable mud swept far out to sea by the greater rivers of the world, especially those of South America, but this hypothesis soon proved inadequate to account for its geographical distribution and its relation to the actual depth of the ocean. The suggestion was afterward made that the tests of the globigerina and its associates, instead of consisting of perfectly pure calcite might contain, embedded in it, a certain quantity of clayey material, just as many foraminifera construct for themselves a covering which is almost wholly composed of grains of sand cemented together. If this were so, a residual clay would be left after the test had been destroyed by the action of water. Others often look upon the clay as either a direct precipitate in the test, like the glauconite already mentioned, or the result of an alteration of that mineral; but the scientific men engaged on the *Challenger* expedition came at last to the conclusion that the red clay was mainly produced by the decomposition

of inorganic material, such as the pumice discharged into the air during volcanic eruptions, which after long floating about on the surface of the sea must become waterlogged and sink, together with the various kinds of dust already mentioned. The evidence which they cite indicates that this red clay accumulates very slowly, and that it owes much to the above materials; but that some part of it may be, directly or indirectly, due to chemical action does not seem improbable.

In shallower water the shells of mollusks, and in certain localities reef-building corals, often form important masses of rock. The first are less dependent on climate and other contingencies than the second; still large accumulations of shells are more frequent, on the whole, in warm than in cold seas. Professor A. Agassiz, for instance, thus describes the extraordinary abundance of mollusks and other marine life near the Florida Keys. After stating that previous writers had called attention to "the formation of an immense submarine plateau, directly in the track of the Gulf Stream, by the accretions of the solid parts of mollusks, echinoderms, corals, halcyonoids, annelids, crustacea, and the like, which have lived and died upon it," thus furnishing limestone, he goes on to say, "No one who has not dredged near the hundred-fathom line on the west coast of the great Florida plateau can form any idea of the amount of animal life which can be sustained upon a small area under suitable conditions of existence. It was no uncommon thing for us to bring up in the trawl or dredge large fragments of the modern limestone now in process of formation, consisting of the dead carcasses of the very species now living on the top of this recent limestone." * Indirectly also that which has lived augments, through the intervention of that which still lives, the accumulating calcareous masses, since certain holothurians, echinoderms, and fishes browse upon the branches of living corals and other organisms which possess similar solid parts, and the material, after passing through the body of the animal, forms a white calcareous mud, at first sight not very unlike chalk.

But the coral polyps may be reckoned among the most important rock builders in the shallower seas. Certain species of coral live in almost all waters, and range down to very considerable depths. These, however, are often small, commonly more or less isolated in their habits, never forming large colonies or constructing reefs; but the builders flourish within more narrow limits, both horizontal and

* A. Agassiz, "Three Cruises of the *Blake*," ch. iii.

vertical. They require pure and well-aërated sea water, with a temperature ranging from 70° to 80° F. (not falling below 68°), and so far as is at present known, the reef builders cannot establish themselves on the sea bed when its depth exceeds twenty-five fathoms. It is true that in isolated cases corals of reef-building species have been dredged up from much greater depths, but as yet no instance of a growing reef has been observed beyond that limit. The polyps also cannot endure long exposure to the air, so that the reef does not grow quite up to the level of high water. Hence the living polyps have a vertical range of about 150 feet, and a reef cannot exceed this thickness unless by a slow subsidence of the sea bed space is obtained for the formation of fresh layers of living corals.

Coral reefs may be separated into three groups—fringing reefs, barrier reefs, and atolls. The first are attached to the coast, and may completely encircle an island, being only interrupted here and there where the embouchure of a stream renders the water too brackish or too muddy for the polyps to exist. The barrier reefs are at a distance from land, sometimes of a few hundred yards, sometimes of several miles. "The great barrier reef off the island of New Caledonia extends in a N.W. and S.E. direction for a distance of upward of 400 miles, and that off the northeastern coast of Australia has a linear extension, with interruptions, of more than 1000 miles. In the case of the latter the width of the intervening strait is between 50 and 60 miles, with a depth of water reaching 350 feet. The reef patches themselves, even in their broader parts, rarely exceed 1 or 2 miles in width."*

The atolls consist of an irregular ring of living and dead coral, inclosing an expanse of water called the lagoon, which usually communicates with the open sea by at least one channel, situated generally upon the leeward side of the atoll. In extent this "varies from 2 to 3 miles, or less: in length to upward of 40 or 50 miles. Where the dimensions are very small the lagoon may be completely absent, or merely indicated by a dry depression—the breadth of the coral ring itself does not usually exceed 1000 to 1500 feet, or somewhat more than a quarter of a mile. In the general composition of an atoll the following parts may be recognized: First, an outer platform of coral-rock, more or less exposed at low water, which is the correspondent of the ordinary rock platforms resulting from tidal destruction; secondly, the beach line

* Heilprin, "The Bermuda Islands," ch. iv.

proper, measuring a few feet in height, and consisting of coral sand, calcareous pebbles, and triturated shells; and thirdly, the exposed ring itself, with the width as above stated, over which, more especially on the windward side, a luxuriant vegetable growth is developed. The elevation of this portion of the atoll more commonly does not exceed 10 to 20 feet, although exceptionally wind-swept dunes of coral sand attain a much greater height. . . On the Bermudas they considerably exceed 200 feet, reaching at one point, Sears' Hill, 260 feet."*

The relationship of these three types of reef and the cause of atoll structure has been, from time to time, a subject of much controversy. This, after a period of comparative repose, again became active about thirteen years since, and has continued intermittently to the present time. For some while prior to the date named the hypothesis advanced by the late Charles Darwin had held almost undisputed possession of the field. Its main features, as stated in his well-known work "The Structure and Distribution of Coral Reefs," † were as follows: The first stage in reef growth is a fringing reef, and the variations in form which coral reefs exhibit are mainly due to subsidence of the foundations on which they rest, or, in other words, of the earth's crust. Suppose a fringing reef to have been established, and the mass to be approaching the surface of the sea, the conditions of growth will no longer be equally favorable in all parts of it. The polyps on the outer margin of the reef will be supplied with better aërated water and with more abundant food than those nearer to the land, so they will grow more vigorously than the others, which will gradually dwindle, and at last will die. So long as the depth will permit, the reef will advance seaward, and will be parted from the shore by a narrow and shallow channel. If the land then begins to sink slowly down, the reef will continue its upward growth, and the breadth of this channel will be increased, until the reef, which originally was a fringing one, has been converted into a barrier reef. But when this is separated from the new coast line by a fairly broad interval of sea, coral polyps can again establish themselves in the neighborhood of the shore, and can begin another fringing reef.

The atoll indicates a special and the last stage in a process of submergence. Suppose a fringing reef to have been formed round

* Heilprin, *loc. cit.*

† The first edition was published in 1842, the second in 1874, a third (posthumous) in 1889.

a comparatively low island. As the latter is gradually submerged the reef continues to grow upward, but its growth inward is checked, as has been already described; so that, after a time, it will be separated from the land, which is now greatly reduced in size. At last this disappears, leaving a ring of growing coral, with a lagoon or open space of water in the center. When the downward movement of the land ceases, the upward growth of the coral will be arrested, after a time, by its proximity to the surface of the water. The reef, however, can still continue to increase in this direction; the waves break off pieces of coral from the sides and heap them up on the platform together with *débris*, chiefly organic, of various kinds, so that the atoll at last is raised above water; seeds are dropped on to it by birds or washed up on it as they drift about, and vegetation clothes its surface. Thus every atoll is a token of subsidence in the past; it is a monument erected by Nature's architects over the grave of a drowned island.

This hypothesis of the origin of coral reefs and atolls accorded so well with most of the known facts that for several years it was generally accepted. But of late more than one observer of no small experience has disputed its accuracy. It is alleged that when any direct evidence as to the direction of motion can be obtained by an examination of atolls and other reefs, this intimates upheaval, not subsidence, as masses of dead coral can be found elevated, sometimes to a very considerable height, above the sea level. Examination of the reefs thus laid bare indicates that marine organisms, other than corals, play an important part in preparing the foundations of the reef, and that this does not attain to the thickness which might have been expected had it been formed by long-continued subsidence. It is also noticed that all, or almost all, the smaller oceanic islands, if not atolls, are of volcanic origin; if this be so, it is not necessary to appeal to subsidence in order to account for the existence of a shoal in the open ocean, for it may be either the top of a volcanic mass which has never reached the surface or the remains of one, like Graham Island in the Mediterranean, the looser materials of which have been washed away by the waves. In cases where the summit of the volcanic mass lay too deep below the surface of the sea to permit of the reef builders establishing themselves, this, in course of time, might be brought within the requisite distance (about twenty-five fathoms) by the accumulation of other organisms, such as mollusca, foraminifera, etc. This would not be difficult, for every layer of sea water one hundred

fathoms deep and a mile square contains more than sixteen tons of carbonate of lime, which can be abstracted by marine organisms, and will amply suffice for building up a substratum for the reef. The ring-like form was thus explained: At first the top of the buried shoal would be covered by a cake-like mass of the coral polyps; but as this grew upward it would assume a ring-like form, since toward the outside the polyps, as already explained, would be more vigorous than those within. The ring also would tend to spread outward, for all round it a talus of broken coral and dead mollusks would be formed, on which, as a foundation, the reef might continue to grow. Thus it would not only assume a more or less circular form, but also expand in process of time like a fairy ring. This method of growth would originate a lagoon, which also might be enlarged; for after a time its semi-stagnant waters would be unfavorable to coral life. Its sides and bed would be covered with dead coral—this would be dissolved by the sea water—and the carbonate of lime would be borne away by the ebbing tide and once more restored to the ocean from which it had been borrowed.

The new hypothesis, however, is itself open to criticism. For instance, the objection to the theory of subsidence, that coral islands commonly testify to upheaval, is less weighty than it seems. No one hesitates to admit, as will be indicated in a later chapter, that the western coasts of Norway and of Britain have been very considerably depressed since the existing contours of the land were sculptured, yet the latest movements no less certainly have been in an upward direction. It may be admitted that foraminifera and other lime-secreting organisms accumulate on the bed of the sea; but it may be doubted whether these, except under special circumstances, such as may be found on the Florida coast (which cannot be extended to the open ocean), will contribute materially to the work of bringing a submarine shoal up to the right distance from the surface. Sixteen tons of carbonate of lime sounds like a very large quantity; but what does it represent when regarded in the cold light of an arithmetical calculation? If precipitated from the sea water over a surface of the same area (a mile square), it would produce a solid layer rather less than .0001 of an inch in thickness. Even if it be built up in the form of hollow organisms, such as globigerina, and these be piled lightly one on another, the layer could not, on the most liberal estimate, reach a tenth of an inch. Contributions from this source to the task of elevating the surface of a submarine hill could not be very important. Professor Heil-

prin, regarding the problem from another point of view, estimates that the annual accumulation could not exceed $\frac{1}{8000}$ part of an inch—that is to say, a period of about one hundred thousand years would be required to build up a layer only one foot in thickness.* If a shoal covered by a hundred fathoms of water is to be brought up to the lower limit of reef-coral life, an accumulation of organisms seventy-five fathoms thick is needed, and this would require forty-

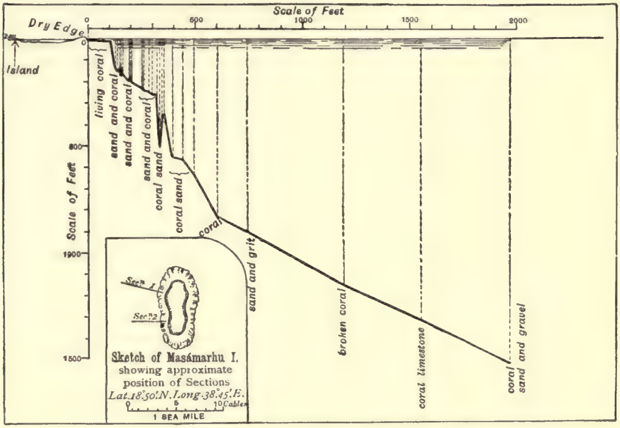


FIG. 78.—MASÁMARHU ISLAND. MAP AND SECTION II.

five million years. The test may be too severe, and the result may somewhat overstate the difficulty, but it seems certain that these small organisms must accumulate so slowly that only very rarely can an appeal be made to such a method of laying the foundation for a coral reef in the open ocean. The white chalk beneath London, which consists mainly of organic material, is commonly about fifty fathoms thick, and the total thickness of the whole mass of chalk is not very much more than double this amount, so that the quantity of organic material demanded for laying the foundations of a reef at a depth of a hundred fathoms would be not very much less than that which is contained in the whole chalk, white and gray. Nature's work is usually slow as man counts time, but we may reasonably feel doubts whether it is conducted in such a very

* "The Bermuda Islands," ch. iv.

leisurely manner as this. The method proposed for the enlargement of lagoons by the corrosive action of sea water on dead coral also presents serious difficulties. It is undoubtedly true, as already stated, that calcareous organisms, under certain circumstances, are dissolved in the ocean. But what are these circumstances? Corrosion takes place when the material is at a depth in the ocean of some two thousand fathoms—in other words, when it is exposed to

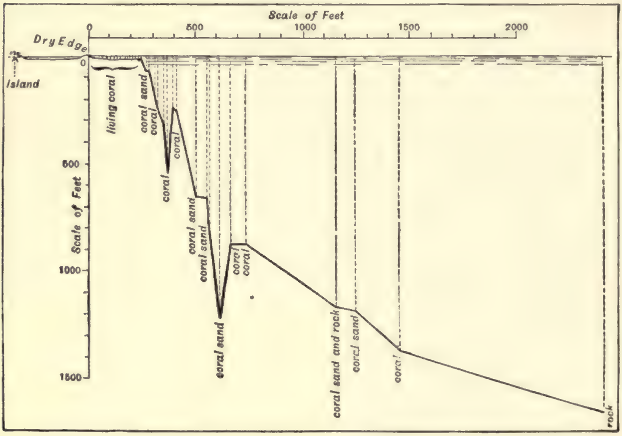


FIG. 79.—MASÁMARHU ISLAND. SECTION I.

a pressure equivalent to that of four hundred atmospheres, or about five thousand six hundred pounds on the square inch. In shallow water, as is proved by the existence and accumulation of the foraminiferal ooze, the corrosive action is so slight as to be unimportant, though probably it would become somewhat greater in the actual wash of the waves and in the changing circumstances of tidal water; but these abyssal conditions, as is well known, present no analogies with the case under consideration, and cannot be introduced into the question. This argument, indeed, and the last, appear to be mutually destructive, for if water has such solvent action, how could organisms construct the foundation of a reef? Moreover, the dead coral of reefs rather rapidly takes up magnesia from sea water, and is thus converted into dolomite—a process to which the conditions within a lagoon would be exceptionally favorable. So

that, as this salt is less soluble than ordinary carbonate of lime, any material enlargement of a lagoon by the corrosive action of sea water does not seem probable.

It is quite true that some reefs are thin, but others rise so rapidly from depths much exceeding 25 fathoms that, so far as at present known, we are driven to suppose that either the reef has been continuously subsiding for a long time, since it first began to grow, or the reef builders can flourish at depths not less than from 100 to 200 fathoms. In favor of the latter supposition no valid evidence has been yet adduced, and 25 fathoms, as already said, has been adopted almost unanimously by all those who have studied the question of the lower limit of reef-building corals. Unless, then, some other alternative can be devised, such reefs as Masámarhu Island, in the Red Sea, indicate a region of subsidence (Figs. 78, 79). No attempt has yet been made—for it would be a difficult and expensive operation—to determine the depth of a coral reef by boring, but the evidence obtained in making some wells in Oahu (one of the Sandwich Islands), so far as it goes, is favorable to the hypothesis of subsidence. During these borings coral rock was pierced at various depths below 150 feet, down to 1048 feet, and in one case a mass of "hard coral rock, like marble," was struck at depths of 320 feet, and proved to be 505 feet thick. As the cores, so far as is stated, were not examined by an experienced geologist, some doubt may be felt as to the accuracy of the identification; still it is difficult to understand how such a phrase could be applied to anything but a semi-fossil reef. If this be correct, either there has been considerable subsidence or the reef not only began, but also ceased to grow, at a greater depth than 25 fathoms, and, further, it attained a thickness of more than triple this amount.

But whatever may be the conclusion which is ultimately adopted as to the genesis and history of a coral reef—a subject which very probably may prove to be more varied and complicated than at first was supposed*—the fact is indisputable that these polyps, at the present day, contribute largely in certain regions of the globe to the formation of limestones. In this task they have taken an important part since a very early period in geological history. Corals, even in cases to which we might hesitate to apply the term reef, are abundant among the mollusks, polyzoa, crinoids, and other echinoderms, which can be readily recognized in blocks of fossil

* A summary of the different opinions and arguments is given in Darwin's "Coral Reefs," Appendix II., third edition.

limestone, and fragments of them may be identified among those of the other organisms which, with foraminifera and algæ, make up the interstitial material of the rock. Reef builders, however, were certainly at work in the sea which covered Shropshire in Silurian ages, Devonshire in Devonian, and Gloucestershire in Jurassic, though in the British Isles the conditions appear to have been less favorable, on the whole, to their development than they were in some other regions, still even here corals are often abundant in limestones. The gray limestone of Derbyshire may be often seen to be crowded either with large bivalve shells, packed as in a modern oyster bed, or with the broken stems of crinoids, close as sticks in a heap (Fig. 80). The oolitic limestones of Somersetshire and Gloucestershire, of Rutlandshire or Lincolnshire, of many localities from Dorsetshire to Yorkshire, are accumulations of organisms, often pounded into sand by the waves, no less than the rock which is still in process of formation on the shores of Ascension or of the Sandwich Isles. Thus the very dust has been once alive, and the chief ministrants to the comfort, the prosperity, and the civilization of man have been the humbler members of that living world at the head of which he claims to stand.

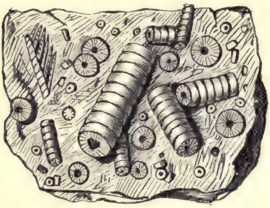


FIG. 80.—LIMESTONE WITH CRINOID STEMS.

FIG. 81.—NUMMULITIC LIMESTONE.

Part III.

CHANGES FROM WITHIN.

CHAPTER I.

MOVEMENTS OF THE CRUST.

THE surface of the earth's crust, as we have endeavored to show in the preceding chapters, is never at rest; from the topmost crags of the loftiest mountain peaks to the deepest abyss in the ocean floor, the work of destruction, of transference, of deposition is constantly carried on; the *débris* worn by the waves, the torrent, or the glacier, or that swept along by the current, comes to rest at last; mineral substances, after vanishing for a time by solution in water, whether of river or sea, are again made visible by life's magic force, enter for a time its service, then drop back once more into the inorganic world, and are incorporated again into masses of rock. The constituents of the crust are ever entering into new combinations; the surface rises and falls, as if it were the breast of some huge monster, slowly breathing as it sleeps, or quivers as if from the pulsations of a hidden heart. The rock which now crowns some towering peak was built up grain by grain in the ocean depths. The alluvium of ancient rivers, the soil of vanished forests, the *débris* of old land surfaces, may be pierced in the deepest mines, far beneath the present ocean level. Ages before the first stone was laid in the walls of London another and a greater Thames swept eastward to the sea. The shelving valley bed, now so thickly studded with houses, is excavated in a tenacious mud such as is still in process of formation off the mouth of the Ganges or of the Nile. The higher hills which at present bound the valley on either side were once built up by a rain of dead organisms on the ocean floor, like the ooze which is collecting deep down beneath the surface of the open Atlantic. The poet uttered no dreamer's words, but simple scientific truth, when he declared:

> There rolls the deep where grew the tree.
> O Earth, what changes hast thou seen!
> There where the long street roars hath been
> The stillness of the central sea.

Evidence of these changes of level can be sometimes obtained from history or from tradition; more often they must be inferred from

the handwriting of Nature, the characters graven on the rocks. Of the former—the historical evidence—a few examples may suffice. The first, and on the whole the most complete—for it is an instance of both subsidence and upheaval, and the whole episode extended over a period which hardly exceeded fourteen centuries—must be

FIG. 82.—COLUMNS IN THE "TEMPLE OF SERAPIS."

briefly recapitulated, though it has been often quoted. West of the headland on which stands Pozzuoli, the ancient Puteoli, is a narrow plain, barely above sea level, which intervenes between the water and the base of an inland cliff. Of itself this is enough to suggest that the water formerly reached a higher limit, but is insufficient to give any definite date to either submergence or elevation. About a quarter of a mile from the town three columns of Cipollino marble, rather more than forty feet high, rise above the plain. In

the earlier part of the last century only about three-quarters of each column stood above ground, but in the year 1750 the site was excavated, and, at a depth of about ten feet from the surface, a pavement was reached, the ruins of which were uncovered. It was discovered that these columns had formed part of a considerable building; portions of the other columns, some of granite, some of various marbles, lay broken on the marble pavement. Some sculptured work and inscriptions were also found. Commonly this building is called the Temple of Serapis, but the accuracy of the name is disputed. That question, however, may be left to antiquarians; for geologists the ruins have other interests. It was observed, and the marks are still as clear as ever, that the shafts of these three columns were thickly pierced with roundish holes all over a band extending from ten up to eighteen feet from the floor. These exactly resemble the deep cavities made in rocks and stones by a mollusk (*Modiola lithophaga*) which is still abundant in the Mediterranean. Above this pitted zone the marble was smooth, and it so continued for the remainder of the shaft—about twenty-four feet.* At that time the dead shells of this bivalve and one or two other mollusks still remained in the burrows. Some of the broken marble columns which lie on the pavement are pierced in like fashion. In these, however, the holes do not extend all round the shaft, but cover only one side of it, and are sometimes sunk in the broken ends, so that when they were made the column was fractured and prostrate. Thus the evidence which the building itself supplies leads irresistibly to the conclusion that after it had become ruinous, and rubbish had accumulated around the bases of these three columns, the ground sank to a depth of at least twenty feet below its former level,† and the pillars must have been partly immersed in the sea long enough to allow the mollusks to burrow into the stone; then they were uplifted to something like their original position.

What light, then, is thrown by history on these singular changes? Its testimony is not very full, but it is, fortunately, sufficient to render the geological story much more precise. Inscriptions discovered in the "temple" show that it was restored (to use the modern phrase) by Septimius Severus, and afterward by Alexander

* The height of the shafts is about forty-two feet.—Phillips, "Vesuvius," ch. viii.

† The top of the perforated zone, according to Professor Phillips, in 1879 was about sixteen feet above high water mark; when the excavations were made the height, as will be further explained, was somewhat greater.

Severus.* As on each occasion an enrichment with precious marbles is mentioned, it may be safely assumed that before the year 235 these columns had been placed in the building. For several centuries after this date no direct testimony can be found as to the fate of the structure, but much is indirectly told. In the year 410 Pozzuoli was sacked by Alaric the Goth; in 445 it suffered the same fate from Genseric the Vandal. These invaders—like all barbarians, whether in the fifth or the nineteenth century—destroyed from mere wantonness, so that if the "temple" by some fortunate chance had escaped the Goth, it is almost certain to have been ruined by the Vandal. An age when empires are tottering to their fall is not

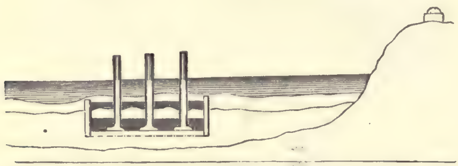


FIG. 83.—THE TEMPLE OF SERAPIS, AT THE TIME OF DEEPEST SUBMERGENCE. The four deposits described in the text are indicated within the walls of the building.

one for the restoration of ancient monuments, so it may be safely assumed that as the building was left by the Vandal so it remained. For nearly eleven centuries nothing more of it is known; then an author named Loffredo states that fifty years before the date when he wrote (1580) the sea washed the base of the cliff already mentioned, so that it was possible to fish from certain ruins at its top. From this it follows that about the year 1530 the pillars must have been standing in the sea. The land, however, had already begun to rise, for in 1503 Ferdinand and Isabella granted to the city and university of Pozzuoli some land "where the sea is drying up," and again in 1511 some more land where "the sea has dried up." Again, we read that in 1538, at the time of the eruption by which Monte Nuovo was formed, half a league away, at the other end of this lowland strip, "the seashore was dried up about Pozzuoli and Baiæ, showing, among other things, newly discovered ruins." Two grants of new land in less than ten years seem to indicate that the rise was comparatively rapid, and the whole change may have been brought about in less than a century, but nothing further is known either on this point or as to the manner of the subsidence. An

* The former reigned A. D. 193–211, the latter 222–235.

eruption of the Solfatara, a crater rather more than a mile away to the northeast, occurred in 1198, and a severe earthquake in 1488, but neither of these can be connected with the submergence by any direct evidence.* The rubbish which protected the lower part of the columns indicates, on the whole, that some time must have elapsed after the building became a ruin before it sank deep enough to be attacked by the boring mollusks. The floor was covered by a dark tufaceous deposit, about two feet thick, which, however, contained some serpulæ. This indicates that the sea had obtained access to the floor of the temple, and mingled its waters with those of the calcareous spring. For a time, then, the depression must have been only a slight one. Over this bed lay an irregular mass of volcanic ash, with an uneven surface from five to nearly nine feet above the pavement. This, however, was probably thrown down in a few hours, or, at most, days; it may have been ejected from the Solfatara in the twelfth century. A mass of calcareous tufa covered these ashes, filling up the hollows, its even top being nine feet from the floor. To form this the waters of the spring already mentioned must have been obstructed by the volcanic rubbish, and a pool formed. As precipitation of tufa would not take place in the sea, the deposit indicates that up to this time the level of the land had but slightly fallen. The tufa was covered by about a couple of feet of ashy material, such as might have fallen in a second eruption, or have been washed in by the sea when it first obtained access; and above that the burrows began. If the irregular mass of volcanic ash is rightly referred to the eruption of the Solfatara, this leaves about three centuries only for the precipitation of the tufa, the submergence to a depth of nine or ten feet above it, and the excavation of the burrows in the marble. If so, as the first

*A letter from Mr. J. E. H. Thomson, published in the *Geological Magazine*, 1892, p. 282, draws attention to a passage in the *Acta Petri et Pauli* which at first sight seems to help in fixing the date of the submergence. This states that Puteoli sank into the water when St. Paul prayed it might be punished for the martyrdom of Dioscurus. From this Mr. Thomson argues that when the book was written the place must have been long under water (*i. e.*, in the fifth century, the date assigned to the *Acta*). So he suggests that the submergence probably occurred "between the middle of the third century and the middle of the fourth." But the evidence, in my opinion, is not worth much. The book is composite and of various dates, parts being much older than the above era; it is also of Eastern, not of Western origin, so that little confidence can be placed in the "local coloring," or in any geographical information. The tradition may be founded on nothing better than the fact that in the Bay of Baiæ the foundations of houses were often laid in the sea itself, which might give rise in process of time to the notion that the land had sunk. (See Horace, "Odes," iii. 1, 33–37.)

and last would occupy some time, the downward movement must have been fairly rapid.

This, however, is not all: at a depth of about five feet the floor of an older building was discovered. So, beneath the pavement of the present ruins—that is, well below high water mark—there is probably a record of some earlier change of level; but in any case the land has not remained at rest since 1750. When the excavation was completed, the pavement of the ruin was above high water mark. Gradually the sea obtained access to it, and about half a century since the rate of subsidence was estimated at an inch in four years.* It is believed that the movement has now ceased, but it had been carried so far that a few years since a new floor had to be constructed, so as to raise the level by about two feet, as the old pavement was under water. In other parts of the Bay of Baiæ evidence of subsidence since Roman times has been discovered, so that these movements have affected a considerable tract of country, though not necessarily to the same extent.

This region, however, is a volcanic one, where disturbances of the earth's crust might be expected, in which also they might well be comparatively local, so that other examples must be sought in districts under more normal conditions. Several instances of changes in level, both upward and downward, are on record, but these more commonly are associated with earthquakes. For instance, in New Zealand the ground has been upraised more than once. A small cove about eighty miles north of Dusky Bay, which formed an excellent harbor for boats and had been long used by the natives, was practically converted into dry land after the earthquakes of 1826 and the following year. Still more remarkable are the accounts of the changes which were produced by the earthquake of 1855, for it was estimated that a district as large as Yorkshire had been elevated from one to nine feet above its former level. Similar effects also have been produced on the coast of Chili, while in the year 1819 by a movement in the contrary direction a tract of land in the Runn of Cutch measuring about two thousand square miles was converted in a few hours into a lagoon. Simultaneously with this depression a neighboring area of marshy land about fifty miles in length was uplifted, and still forms a low mound.

A comparison of historical evidence and the examination of

*The estimate was made between 1822 and 1838.—Lyell, "Principles of Geology," ch. xxx.

various landmarks sometimes show that, in not a few regions, movements of the land have occurred quite unaccompanied by earthquakes, and so slow as to be imperceptible to ordinary observation. For instance, the Baltic coast in the North of Sweden has slowly risen during the last century, while at the southern end of the peninsula it has about as slowly sunk. In a little more than the same time Malmo, in the extreme south, is believed to have subsided about five feet. This subsidence is by no means restricted to the South of Scandinavia; within the period covered by history it appears to have affected the coasts of Schleswig, of Holland, and

FIG. 84.—TERRACES CUT BY THE SEA, MALANGER FJORD, NORWAY.

even of Northern France. A slow downward movement—slight, but not inconsiderable—seems to have affected the coast round the head of the Adriatic, at any rate during the last fourteen or fifteen centuries; the coast of Greenland also, from the sixtieth to the sixty-ninth parallel, has been slowly settling down. The native avoids building his hut near to the water's edge; the Moravian missionaries have been compelled to move the posts to which their boats are moored further inland.* But here, as in Scandinavia, the motion further north is in the opposite direction. An upward movement, indeed, seems to have affected a very large area in the northern hemisphere. In Siberia, Nova Zembla, Franz Joseph Land, Northern Greenland,† raised beaches are common, and

* Lyell, "Principles of Geology," ch. xxxi.

† Payer, "New Lands within the Arctic Circle," vol. ii. pp. 86, 273.

marine organisms, still in a comparatively fresh condition, have been found some distance inland, and many feet above sea level. At Port Kennedy, near latitude 81° N., the bone of a whale lay on the mossy earth 164 feet above sea level, and shells were found nearly 400 feet higher.*

If account be taken of less direct testimony, there can be no question that very important changes of level have taken place since a time, geologically speaking, so recent that the physical features of the country have been in other respects little altered. At Kured, near Uddevalla, in Sweden, a deposit of seashells,

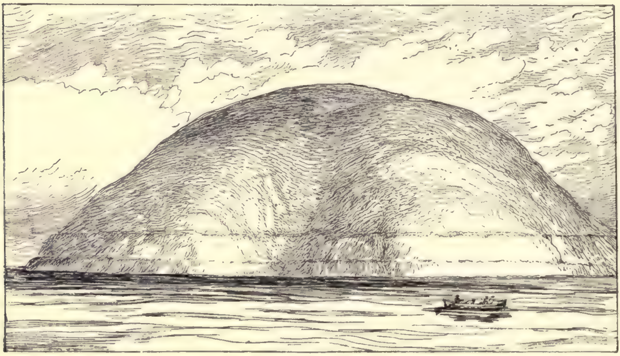


FIG. 85.—SEA-CUT GROOVES IN SMOOTHED ROCK, N. OF ALTEN FJORD, NORWAY.

consisting wholly of living species, may be found, together with barnacles and corallines still adherent to the rock. Similar deposits occur here and there along the Norway coast, while the raised beaches already mentioned are often seen from one to two hundred feet above sea level, and may be traced sometimes to at least five hundred feet. Other proofs of marine action, such as wave marks, may often be found. In Nova Zembla these terraces exist at an elevation of at least six hundred feet, and on the Fraser River to something like double this amount. In several parts of the western coasts of South America proofs of a general rising of the land are clear and frequent, and in the neighborhood of Valparaiso more than one line of terraces exists, the highest being as much as 1295 feet above the sea.

* Many instances are cited by Réclus, "The Earth," ch. lxxx.

The coasts of the British Isles also indicate an upward movement, which is more marked in the north than in the south. In the latter, however, raised beaches may be found, especially in the west; but on the Scotch coasts terraces, old sea cliffs and caves, sandy flats or rocky platforms a few feet above sea level, carses, or the elevated deltas of rivers, are to be found in numbers of places. In the carse of the Clyde, below Glasgow, several canoes, belonging to the age when tools and weapons of polished stone were in general use, have been dug up. These were lying some feet above high water mark, and the general altitude of the last and best preserved of the beaches indicates a change of level which varies from twenty to thirty feet in the central valley of Scotland. Similar indications of a rise of land are to be found in Ireland, especially in the more northern part; but it may be remarked that many of the above-mentioned districts also testify that this uprising is only a partial undoing of a preceding movement of depression on a yet greater scale.

Some authors have suggested that the sea, rather than the land, may change its level, for its height must depend upon the quantity of water in the ocean; the level of that also may not be the same at all places—in other words, its surface, instead of forming part of a sphereoidal shell, interrupted only by the prominences of islands and continents, may be varied by slight depressions and elevations. To some extent this is true, for differences in atmospheric pressure and winds produce an effect on the level of the surface, but this is unimportant. It is suggested that larger variations are possible. Suppose, for instance, that the climate, either over the whole globe or in one of its hemispheres, north and south of the equator, became much colder—and this actually did happen in an epoch, geologically speaking, not at all remote—then there would be less rain and more snow, and a larger amount of water would be converted into ice. Thus the height of the ocean would be lowered, because a considerable quantity of its water would be temporarily added, in the form of ice, to the solid crust of the earth. Again, if in either hemisphere, in consequence of this change of temperature, a great ice cap had been formed in circumpolar regions, the center of gravity of the globe would be no longer at the center of the sphere or spheroid, but it would be slightly displaced along the axis of rotation in the direction of the cap. But by this displacement of the center of attraction the form of the surface of the ocean must be affected, for its waters must assume a new position and be

slightly moved in the direction of the pole. If the cap be in the North Polar area, the sea, in consequence of this change of form in the watery envelope, will stand at a higher level in northern regions than was formerly the case, and the difference will become greater in proceeding toward this pole. Of course it will be correspondingly lowered in the southern hemisphere. Continental lands and mountain masses also must produce some disturbing effect on the level of the ocean. Suppose the earth with a perfectly smooth surface, as represented by a model globe, then the center of gravity corresponds with the center of the figure, and the ocean must form a film on its surface of the same depth throughout. Next suppose that islands and continents are modeled in clay on the surface of the globe, the position of the center of gravity of the whole mass might, and probably would, be affected; but the disturbing effect on the ocean itself will be more readily perceived by taking separate account of the additional matter. In the neighborhood of any one of these patches the water is attracted, as before, toward the center of the earth, but it is also attracted, more or less horizontally, toward the additional material. Round this, then, it will be somewhat heaped up. The disturbance will be slight round an island, greater round a continent, still greater if an important mountain chain rises near the coast. Thus changes in the height and the distribution of the land masses must react upon the sea, the level of which may be affected indirectly by distant movements, rather than directly by the rise and fall of the actual coast line.

These undoubtedly are true causes: they cannot fail to produce an effect; but whether they are adequate to produce the particular effects which have to be explained is another question. The amount of the disturbance which would result from a polar ice cap has been calculated.* Supposing the latter to be 6000 feet thick at the pole, and to come down to about lat. 60°, the greatest height to which it would raise the water would be 380 feet. This amount would be clearly inadequate, for a much greater elevation than this has often to be explained; but there is another difficulty yet more serious: the old water marks above the present sea level should indicate a uniform rise, the elevation increasing as they are followed northward along a parallel of longitude. This often is not the case. In Norway, on the actual seacoast, raised beaches and other indications of the change of level are seldom, if ever, seen in

* By Sir W. Thomson (Lord Kelvin).

the southern part of the peninsula, but as Trondhjem is approached they begin to show themselves, and become conspicuous to the north of that town. Yet if any one of the fjords be entered, raised beaches soon present themselves, and generally continue to increase

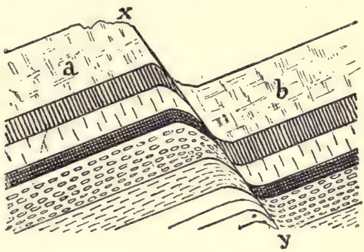


FIG. 86. DIAGRAM OF A FAULT.
x y, Line of fault; *a b*, A displaced bed.
The beds are bent near the fault by the strain in slipping.

in elevation toward its head. Moreover, in one and the same district they sometimes vary considerably in level, and are not uniform. According to observations made in the Alten Fjord the variations in the level of the same terrace amount to more than a hundred feet.

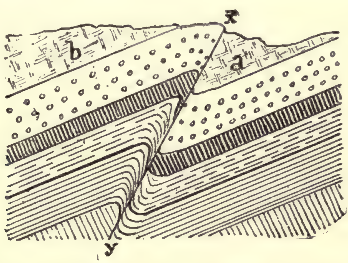


FIG. 87.—DIAGRAM OF A REVERSED FAULT.
Here the bed *b* has been pushed up over *a*.

Similar objections might be made to the other theories. If the total quantity of the water were diminished, the change should be everywhere the same; if the ocean were heaped up around the larger land masses, each one of these should show a uniform rise; both theories alike would be inadequate to explain the effect which has been observed. We may therefore conclude, without entering

upon other considerations, that, although the sea level cannot be regarded as an absolutely fixed datum line, the surface of the land does actually rise and fall.

No long study of the stratified rocks which form part of the earth's crust is needed to show that these movements are not a new thing in its history. The gray limestones, in which the dales of Derbyshire and Yorkshire are excavated, are crowded with the remains of creatures which must have lived and died not only in the

FIG. 88.—FLEXURES IN BEDDED LIMESTONE, DRAUGHTON, NEAR SKIPTON.

ocean, but also in one where the waters were clear. The slaty rocks on the topmost peak of Snowdon are full of fossil shells which must once have inhabited the sea. On Alpine summits, at elevations of more than ten thousand feet, marine shells are found embedded in the rocks, while in the Himalayas, at some seventeen thousand feet, geologists have discovered the tests of a large foraminifer very nearly allied to one which may be picked out of the clays sometimes laid bare by the sea on the shore of Bracklesham Bay on the Sussex coast.

These facts cannot be explained by any theories as to the diminution of the total quantity of water on the surface of the globe, for not seldom identically the same fossils can be discovered in one

place quite close to the present sea level, in another many hundreds of feet above it. Frequently both the fossils themselves and the characteristics of the rock indicate that it has been formed not even on a coast, but in the clear waters of the open ocean. On tracing the rock masses over a considerable area, these also testify to changes of level subsequent to the era when they were deposited, horizontally, or nearly horizontally, as it may be presumed, on the bed of the sea. The strata often are inclined at considerable angles to the horizon; sometimes they are even in an upright position; they are bent into curves, arches, folds of all kinds (Fig. 88); they bear the marks of great compression, which evidently has often

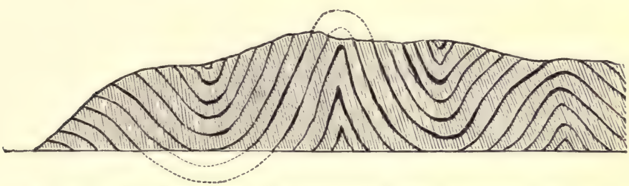


FIG. 89.—DIAGRAM OF FOLDS IN STRATIFIED ROCKS. (COMPARE FIG. 88.)

acted in directions quite independent of the planes of stratification; they have been snapped across under great strains, and the broken ends are now separated by hundreds, sometimes even thousands, of feet—in technical language, most of the older rocks, and some of those which are comparatively modern, have obviously suffered from folding and faulting, both of which are indicative of a change of level. Every mountain range testifies to these movements, often recurrent, of the earth's crust. Two instances—the Jura and the Alps—may suffice as an illustration, the one of the simpler, the other of the more complex structure. As we hurry, all too quickly, along the railway, through the winding glens of the Jura, we cannot fail to notice that the beds of cream-colored limestone, which are exposed in cliff and scar, often slope at high angles, sometimes in opposite directions, and are occasionally curiously contorted. A more careful study would show that in this mountain mass alternating limestones and shales, of considerable thickness, have been bent into a group of parallel folds, from which the present scenery, the rolling ridges, and the winding dales, have been sculptured by the action of those natural agencies which have been described in earlier chapters of this book.

The structure of the Alps is more complicated, but its testimony, if possible, is yet stronger than that of the Jura. Different parts of this great mountain chain exhibit differences in detail, often not unimportant, but in all cases the conclusion to which their testimony leads is the same. A traverse of the chain, in the general direction of the St. Gothard railway, exhibits its structure as well as any other, perhaps better than most; it has also the advantage of being more or less familiar to many persons. We emerge from the

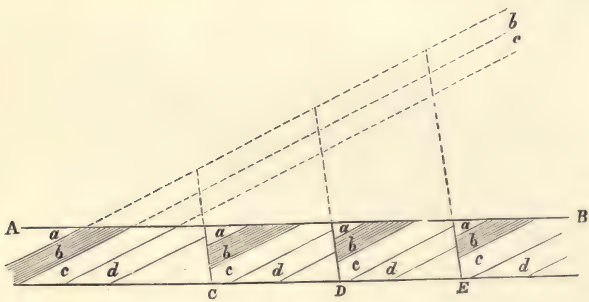


FIG. 90.—DIAGRAM OF FAULTS IN STRATFIED ROCKS.

The beds *a*, *b*, *c*, *d*, if unbroken, would follow the dotted lines, but by being broken and dropped down, as shown by the nearly vertical lines at C, D, E, they are repeated again and again. A B represents the present snrface of the ground.

Jura upon a comparative lowland—an undulating district, where the rounded hills and gentle slopes seldom rise more than a very few hundred feet at most above the beds of the rivers. It is a fair and fertile land—one of meadows and copses, of cornfields, orchards, and vineyards. When the last named are out of sight, as is often the case, we might imagine ourselves in some rural district of England, were it not for the quaint houses dotted about here and there on the slopes or grouped on the brink of a stream, or for glimpses of a mighty mountain wall, away to the south, with icy peaks that gleam against the blue sky. But presently that mountain wall rises higher in the air, and is more and more sharply defined. The details of precipice and peak, of snowfield and glacier, become more distinct; the hills on either side of the railway begin to raise more boldly; their slopes are steeper, and sometimes even broken by cliffs. We have now reached the gate of the mountains. The Lake of the Four Forest Cantons spreads its clear waters between the meadow of

Grutli and the crags of the Rigi. These crags consist mainly of pudding stone, a coarse gravel which has become cemented into a mass as hard as concrete. This gravel and those sandstones which rise by the lake shore, and have been seen at intervals on the lowland, are composed of the *débris* of an ancient mountain chain, and that chain, as can be inferred from the distribution and contents of the pebble beds, is still represented by the Alps. These sands and gravels were deposited not far from the sea level, for some of the former even contain marine shells, while the latter are the *débris* which was spread abroad by rapid rivers as they emerged from the

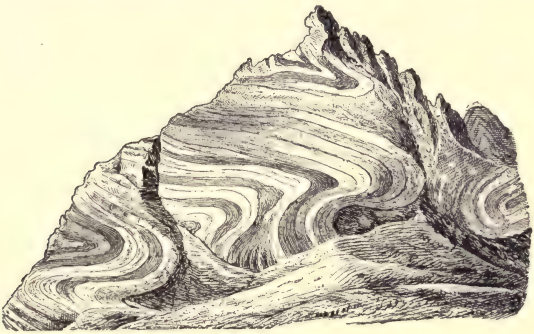


FIG. 91.—FOLDED STRATA (LOWER TERTIARY) IN THE HAUSSTOCK (*O. Frass*).

gates of the hills. But now these gravels sometimes rise full five thousand feet above sea level, so that since they were deposited the land must have been greatly uplifted. This, however, is not all. The mountains which they form are but the outworks of the Alps; behind them rises a line of loftier and bolder summits, ranging often from about six thousand to ten thousand feet above sea level, occasionally reaching a still greater elevation. In these limestone is the dominant rock, but slaty or shaly beds are common—pebble beds and sandstones are rare. At first sight their relation to the last-named group is rather perplexing—in most places they appear to rise from beneath them, but in others to overlie them. Further examination, while it justifies the perplexity, explains the apparent contradiction. These beds are often curiously bent and folded, as may be seen in the fine cliffs which are mirrored in the Bay of Uri. But in some places this process has been carried so far that the folds

have been pushed over from the southern side till their loops have been doubled back. As the thrust continued, these sometimes yielded to the strain, and the upper half was then pushed for some distance above the lower, thus bringing the inner or older member of the fold to rest upon the outer or newer (Fig. 92). In the language of geology this is termed an overthrust fault; it brings the beds into a wrong order, and is often (in the absence of fossils) extremely difficult to detect. As the road passes away from the head of the lake, up the valley of the Reuss, the whole thickness of the mountain mass for a time is composed of these limestone rocks; but at Erstfeld their foundation stones are disclosed, as a new group of rocks appears beneath them and rises rapidly upward. After passing Amsteg little more is seen of the sedimentary deposits, for the left bank of the Maderanerthal consists almost entirely of crystalline rocks (Fig. 93).* For several miles the wild glens of the Reuss and the snow-streaked peaks above are wholly sculptured from this group—a hard, gray, granite-like rock being the commonest. Through this are driven the curious corkscrew tunnels of the railway; into this it disappears at Göschenen, as it begins its subterranean journey, more than three leagues long, through the watershed of Europe. The same rock continues to the Devil's Bridge, but after the road has emerged from the "Hole of Uri" the scene suddenly changes. Instead of the narrow glens and frowning crags a comparatively broad and fertile valley opens out in front, guarded on one side by the chain which has been traversed, on the other by one in many respects similar, but rather less bold in outline. The latter is the watershed of Europe. Parallel with this the valley of the Reuss extends for a few miles, but from any commanding peak it would be seen to be carved out of the floor of a great trough

FIG. 92.—PROCESS OF CONVERSION OF A FOLD [a] THROUGH AN OVERFOLD [b] INTO AN OVERTHRUST FAULT [c].

* These are schists, gneissose and granitoid rocks.

which is occupied by the head waters, not only of the Reuss, but also of the Rhine on one side and of the Rhone on the other.

So marked a change of scenery is a sure indication of a change in the rocks. The geological structure just in this part is extremely complicated, and some of its details are still the subject of controversy; but this trough, speaking in general terms, is formed by a mass of slaty rock, the greater part of which is very nearly of the same age as the limestones which were last seen in the neighborhood of Amsteg. It is part of a huge fold, caught between the masses of underlying crystalline rock. From the meadows of Andermatt and Hospenthal the road mounts toward the St. Gothard Pass, again traversing schists, gneisses, and granites, though different in some respects from those previously seen; but at Airolo, where it arrives at the foot of the steeper descent, and at the southern mouth of the tunnel, it finds a similar trough-like valley and deposits of a like age to those on the other side of the range, though the fold is on a smaller scale. But even here these gigantic wrinklings of the earth's crust are not ended. As is shown in the excellent section given in Professor Prestwich's "Geology,"* four sharply infolded troughs have yet to be crossed, with the intervening uplifts, before the road comes to the border zone of sandstone shortly beyond which the plain of Northern Italy is reached, and the Alps are finally left behind. To what kind of movement in the earth's crust is a structure such as that which the Alps exhibit to be ascribed? By placing a number of thin slabs of some imperfectly flexible materials one upon the top of another, and by then bringing

FIG. 93.—SECTION ACROSS THE ALPS, IN THE GENERAL DIRECTION OF THE ST. GOTHARD ROAD (*Heim*).

* Vol. i. ("Chemical and Physical") p. 304.

the opposite ends gradually closer together, the folds, and even some of the peculiar fractures and faulting, of a mountain chain can be imitated (Fig. 94).* It seems, then, most natural to attribute a mountain chain to the effects of lateral pressure, this being due to a contraction of the earth's crust through the loss of internal heat.

Such an explanation, however, is not without its difficulties, as will be seen later on, and a different solution of the problem was offered a few years since by Mr. Mellard Reade. This makes the "ridging up" of the crust an indirect, rather than a direct, consequence of radiation of heat. Most substances expand when their

FIG. 94.—DIAGRAM ILLUSTRATING PROFESSOR FAVRE'S EXPERIMENT.

Showing the artificial folds produced in a series of layers of clay on indiarubber, according to an experiment of Professor A. Favre. The arrows show the direction of the contraction.

temperature is raised. If, however, as he shows by experiments, any material, such as a plate of metal, be fastened down securely at the edges, so that expansion in any but a vertical direction becomes impossible, and its temperature be raised, then it is bent into puckers and waves something like those of a mountain chain. A mass of rock, forming part of the crust of the earth, is under somewhat similar conditions. When its temperature is raised, expansion downward is resisted by the mass beneath, and laterally by the rest of the crust, while in an upward direction gravity alone has to be overcome. If, then, any part of the crust be raised to a higher temperature, the result must be puckering and folding, especially in the more superficial part.

So Mr. Reade supposes that a mountain range has been produced in the following way: In the first place, some unequal movements

* This has been done in models prepared by Professor Favre, which are preserved in the Geological Museum at Geneva, and in a remarkable series made by Mr. H. M. Cadell, and described by him in a paper published in the "Transactions of the Royal Society of Edinburgh," vol. xxxv. p. 337.

caused upheaval in one considerable area of the crust and depression in another adjoining; the former must become a region of denudation, the latter one of deposition. Suppose this process to be continued for a long time, and a great thickness of sediment to have been, as it were, plastered over a zone of the crust (for it must be remembered that, as already pointed out, most of the sediment brought down into the sea is deposited, as a rule, within a limited distance from the land). Then if the interior of the earth, as is generally believed, be at a high temperature, and heat is being lost by radiation, the effect of this local addition to the thickness of the crust will be like that of cementing a strip of non-conducting material on the surface of a cooling ball of metal: the temperature of the mass immediately beneath, and ultimately that of the strip itself, will be raised. Thus both the sedimentary deposits and the floor on which they rest expand, and, as movement is only possible in an upward direction, puckering and folding are produced.* But the underlying rock consists of much less pliant materials than the overlying; for, as greatly the older, they are more consolidated, perhaps are even crystalline, and this inequality must introduce complications in the process of folding. Moreover, as the temperature of the floor gradually rises, this may be sufficient locally to soften portions of it which previously had been solid; hence the foundation itself might be fractured under strain, and thus new complications might be introduced. Again, as the freshly disturbed mass began to rise it too would be exposed to denudation. But as the exterior was carved into hill and valley, the temperature of the crust beneath would be affected. The surfaces of equal temperature in it would reproduce, to a certain extent, the irregularities of the outer surface, and the contractions thus caused would introduce further complications into the foldings. The result of all these irregularities might be the inversions, overthrusts, and other more local and exceptional disturbances which occur in a mountain region. Mr. Mellard Reade's reasoning is sound and coherent; a period of mountain making appears generally to have been preceded by one of depression and deposition; foldings and other disturbances undoubtedly might be, and probably often have been, produced as he describes; his hypothesis avoids the main difficulty (which is not inconsiderable) in the other explanation. At the same time doubts may be felt whether it is not attended, when applied as a working

* The effect, of course, is much greater in the lower part of the zone of added material; radiation produces practically no alteration in the surface temperature of the earth.

hypothesis, with difficulties which are quite as serious. The folding of a chain like the Alps is so marked, and its scale so gigantic, that the difference of temperature and consequent expansion which would be produced by the accumulation on that area of a few thousand feet of rock seem quite inadequate as a cause, while the evidence that the thrusts have been mainly lateral seems very strong. Not only the softer sedimentaries, but even the hard crystalline masses are commonly affected by a cleavage structure, which makes a high angle with the horizon, and must accordingly be the result of a pressure which has acted nearly parallel with the latter. Though the amount of surface which must be lost by the formation of a mountain chain by contraction of the crust seems large when expressed in miles, this can be obtained by a shortening of the radius, relatively very small, the effect of which on the rate of rotation of the globe may be counterbalanced by other agencies, and by the "drag" of the tidal waves. Thus it is probably more correct to attribute the origin of mountain ranges to a contraction in the crust which is the result of loss of heat in the globe as a whole, rather than to the combined effect of radiation and deposition, which Mr. Reade regards as the dominant cause.

Two eminent Austrian geologists * have called attention to another way in which the loss of heat in producing contraction may affect the level of the crust. As this crust is not homogeneous in composition or uniform in strength, some portions of it may subside, while others remain at rest. The following illustration which they offer gives in a few words a general idea of their hypothesis: Suppose that, for simplicity, any portion of the upper part of the earth's crust be represented by a sheet of ice covering the surface of a lake, and that from its bed either piles or pieces of masonry rise up here and there so as to just touch the bottom of the ice. If some of the water be drawn off, the ice above these obstacles † remains immovable, but that in the interval sinks, cracking and bending as it slips down along their flanks, in the immediate vicinity of which the most marked disturbances will be produced. The piers represent ancient masses of solid crystalline rocks; the ice the less coherent sediments deposited on and about them. In this view the changes of level are due to subsidence rather than to upheaval, for

* Professor Suess ("Antlitz der Erde") and Neumayer ("Erdegeschichte").

† Such a mass is called *Horst*, from a miner's term which means a pillar, mound, or point of rock.

the original level of the seas is represented by the fragments of sedimentary deposits which still cover the piers, and those which remain often comparatively unaffected by denudation, in the intervening spaces, have descended, like the present ocean, toward the center of the earth.

This hypothesis gives a very natural explanation of the present disposition of the Secondary Rocks in some parts of Europe; for instance, in France they are disposed about the central plateau of Auvergne, with the Cevennes, the *massif* of Brittany and that of the Vosges, in a series of basins, with the edges of the older deposits nearer to the districts which consist of ancient crystalline rocks, each succeeding the other, like the edges of a series of thick saucers which gradually diminish in size and are placed one within the other. It is also applicable to other parts of Europe, but it seems hardly adequate to account for such a broad zone of sharp folds as is presented by the Alps and several other mountain chains. May not contraction produce sometimes the one result, sometimes the other, according to circumstances, this being the effect, so to say, of the surface dimpling, that of its wrinkling? In either case the resistance to movement which is offered by large masses of rock more solid than other parts similarly affected cannot fail to modify profoundly the results produced either by vertical shrinkage or by tangential thrust. This is one of the many geological questions on which, as our knowledge is so rapidly growing, it is wiser to "keep an open mind," for what would be a weakness in politics may be a duty in science.

CHAPTER II.

VOLCANIC ACTION AND ITS EFFECTS.

VOLCANOES are external indications of inward disturbances—symptoms, like boils upon the body, of constitutional derangement in the globe, and in this case, as in the other, doctors are not always agreed in their diagnosis of the malady. A volcano is an orifice in the crust of the earth, commonly terminating in a bowl-like hollow, called a crater, which forms the summit of a mountain or hill, usually more or less conical in outline. From the crater are ejected—sometimes continuously, sometimes with long intervals of quiescence, but always more or less explosively—gas, steam or water, dust (formed of comminuted minerals or rock), scoria or bits of natural slag, and molten rock or lava. Sometimes there is a well-marked central cone, which crowns a lofty mountain mass. The outlines of this may bear general resemblance to those of the upper portion, though usually it has been furrowed by streams and wasted by rains—in a word, considerably modified by processes of denudation. The highest point in the crater may rise to an elevation of several thousand feet, not only above the sea, but even above the surrounding plateaus, as Cotopaxi rises more than nine thousand feet above the plain at its base,* or the Peak of Teneriffe towers above the ocean to an altitude of over twelve thousand feet. Sometimes the craters, as in the Phlegræan Fields, are low in proportion to their height, and form irregular inconspicuous groups without any dominant summit. Sometimes the cones take a linear order, more or less simple, and help to make up a vast mountain chain, as in the Andes; sometimes they rise in solitary grandeur, like Etna. But as volcanoes are studied the one type seems to merge into the other, and a classification by forms or by distribution appears almost impossible. Neither does it seem more feasible to classify volcanoes by the character of their emissions. From the same orifice different materials may be discharged at different times: at an epoch of quiescence, gas or steam; at one of greater

* Whymper, "Travels in the Great Andes of Ecuador," vol. i. ch. vi.

activity, hot water, mud, or clouds of dust; at its greatest intensity, showers of scoria and streams of lava. Specialized varieties, as they may be called, may, no doubt, be found: volcanoes where local circumstances restrict the eruptive discharge within a more limited range, like the craters of boiling mud at Kravla, in Iceland, or the geyser fountains of boiling water in that country or at the Yellowstone; but all these are so closely connected as to be only varietal manifestations of the same set of causes.

In a volcanic eruption the earth trembles, and the air is dark with the ejected dust, which spreads over miles of country a murky pall even more hideous than a midday fog in London. The crater is veiled in clouds of steam, fetid with acid vapors; these at one time white as a mass of cumulus, at another are blackened with the dust, and at night are glowing with the reflected glare of the molten mass within the crater; on the flanks of the mountain blocks of rock fall hurtling through the air, and at last the molten lava from the vast subterranean furnace creeps down the slopes beneath a pall of steam, its path marked by destruction, and irresistible as death. The scene is a realization of a prophet's vision of the time when

FIG. 95.—AN EJECTED CLOT OF LAVA.

Dies iræ, dies illa, Solvet sæculum in favilla.

But there is nothing without a reason, and the question arises, What cause or combination of causes produces these rude interruptions, happily local, to the general tranquillity of the order of Nature? An answer to this must be sought in studying not only the phenomena of a volcanic eruption, but also the structure of volcanoes themselves. Just as the physician obtains his knowledge not only by watching the progress of a disease in his clinical studies, but also by investigation of the morbid tissues in the dissecting room, so the geologist must draw his inferences from volcanoes; for they, like all other things, have their time to die, and then the corpse, though too gigantic for the puny tools of man, is dissected by his ministrants, and made into preparations for his study. In other words, volcanoes may be found which exhibit every stage, from the perfect crater—of which, as it seems, the last discharge of steam or gas was an event almost of yesterday—to the ruined mass where crater and cone alike have disappeared, and the bare skeleton can be recognized only by the practiced eye.

The clinical study shall have first place in this notice, but it will be well to call attention at the outset to a fact which will prove to have a pathological significance. Water and volcanic eruptions seem closely connected. Volcanoes on the land are, indeed, more conspicuous than those under the sea; but submarine volcanoes are not rare, and even the former are almost invariably near to the ocean or to some large sheet of water.

The number of volcanic eruptions which have been recorded with more or less care and precision is now so large that it is by no

FIG. 96.—MUD VOLCANOES, TURBACO, COLOMBIA.

means easy to make a selection of cases which may serve as types. That which we place first in order is chosen as one of the simplest examples, yet, at the same time, one of the most complete, for it exhibits the building of a volcanic cone from beginning to end, all in the course of a very few days. It is that of Monte Nuovo on the Bay of Baiæ. This cone rises on ground classic to the student of literature as well as of science. Here Horace and the men of the Augustan age loved to linger;* yet here, too, was the dark entrance to the world of shadows.† Shore and land are studded both with the ruins of Roman luxury and with the craters of volcanoes, so con-

* Nullus in orbe sinus Baiis prælucet amœnis."—Hor., "Ep." I, i. 83.

† Lake Avernus, occupying an old crater.

spicuous that ages since the land was named Campi Phlegræi, or the Burning Fields. These volanic hills on the west of Naples are a curious contrast to Vesuvius on the east. There a mountain mass, with a central cone, rises to a height of nearly five thousand feet above the sea. Here are several craters, broad in comparison with their height, for they do not attain to more than a few hundred feet above sea level; yet the crater ring of the largest—Astroni—is three miles in circumference, and its inner area spacious enough to serve as a royal deer park. Some of these craters have long since ceased to be active, and are in ruins; others have been occasionally,

FIG. 97.—MONTE NUOVO, FROM THE SEA-SHORE.

though rarely, in eruption, but in them an isolated jet of steam or a pond of boiling mud indicates the possibility of future disturbances. Rather more than a mile to the west of the ruins of the Temple of Serapis, mentioned in the last chapter, lies the Lucrine Lake, the basin of an old crater which in the days of Augustus was connected with the sea. Such a natural harbor on this shallow coast would be welcome to the Roman mariner; the place also was acceptable to the Roman epicure as producing the best oysters in Italy.[1]

Thus runs the story of the building of Monte Nuovo, as it is told by some contemporary writers: For two years prior to September, 1538, Naples, Pozzuoli, and its neighborhood had been frequently shaken by earthquakes. At last, on the 29th of that month, about an hour after midnight, flames of fire * appeared on the shore on the present site of Monte Nuovo; the ground rose, and a not inconsiderable tract of the shallow sea became land. Then cracks were

* Probably steam reflecting the glowing material beneath.

seen to open near to the Lucrine Lake, and from the "horrid mouth" thus disclosed "were vomited furiously smoke, fire, stones, and mud composed of ashes"; the discharge was accompanied by a noise like the loudest thunder, and some of the masses ejected "were larger than an ox. . . The stones went about as high as a crossbow can carry, and then fell down, sometimes on the edge, and sometimes into the mouth itself. The mud was of the color of ashes, and at first very liquid, then by degrees less so, and in such quantities that in less than twelve hours, with the help of the above-mentioned stones, a mountain was raised of one thousand paces in height. Not only Pozzuoli and the neighboring country was full of this mud, but the city of Naples also, so that many of its palaces were defaced by it.* Now this eruption lasted two days and two nights without intermission, though, it is true, not always with the same force. The third day the eruption ceased, and I went up with many people to the top of the new hill and saw down into its mouth, which was a round cavity about a quarter of a mile in circumference, in the middle of which the stones which had fallen were boiling up, just as a caldron of water boils on the fire. The fourth day it began to throw up again, and the seventh much more, but still with less violence than the first night. . . In the day the smoke still continues, and you often see fire in the midst of it in the night time."†

The cone of Monte Nuovo rises to a height of 440 feet above the sea; the vent is completely sealed, neither steam nor gas being exhaled. The outer slopes are clothed with coarse herbage, heath, and broom, or with oak scrub, mulberry, ilex, and stone-pine; the inner slopes descend very steeply to a saucer-shaped basin, cultivated (in 1876) as a garden. A study of the cone fully confirms the inference suggested by the testimony quoted above, viz., that it was built up by the materials discharged from the orifice, and that any elevation of the land was a factor in its structure comparatively unimportant.‡

We pass from Italy to the Sandwich Islands. About 4000 feet above sea level, on the flank of Mauna Loa—almost the highest

* Probably this was dust shot up in a state of fine division among steam to a very considerable height, and brought down mingled with rain.

† Quoted in Sir C. Lyell's "Principles of Geology," ch. xxiv., from Sir W. Hamilton's "Campi Phelgræi," p. 70.

‡ Four different accounts are quoted by Sir C. Lyell ("Principles," ch. xxiv.), which, though they differ as to minor details, agree in their more important features.

mountain, and itself a volcanic cone, frequently in eruption—some twenty miles away, is the singular subsidiary crater of Kilauea. It is a huge basin, practically without a cone; in other words, hardly more than an orifice in the gently shelving flank of the *massif* of Mauna Loa, in form an irregular oval with a projecting end;

FIG. 98.—THE ISLAND OF HAWAII IN THE HAWAIIAN OR SANDWICH GROUP, SHOWING THE DIFFERENT CRATERS AND THE LAVA STREAMS OF VARIOUS ERUPTIONS.

(*a*) Hualalai; (*b*) Mokuaweoweo; (*c*) Kilauea—craters; (*d*) lava streams. The contour lines show differences of 2000 feet in height.

it is about 2½ miles long, and its precipitous walls inclose an area of nearly four square miles. A well-marked and generally broad ledge or step divides the crater into two stages. The floor in 1887 was "a desolate scene of bare rock. Instead of a sea of molten lava 'rolling to and fro its fiery surge and flaming billows,'* the only signs of action were in three spots of a blood-red color, which were in feeble and constant agitation, like that of a caldron in ebullition. Fiery jets were playing over the surface of the three lakes, but it was merely quiet boiling, for not a whisper was heard from the depths. And, in harmony with the stillness of the scene, white vapors rose in fleecy wreaths from the pools and numerous fissures, and collected over the large lava lake into a broad canopy of clouds. . . When on the verge of the lower pit, a half-smothered

* As it had been described, perhaps somewhat poetically, by a previous observer.

gurgling sound was all that could be heard. Occasionally a report like musketry came from the depths; then all was still again, except the stifled mutterings of the boiling lakes. In a night scene from the summit the large caldron, in place of a bloody glare, now glowed with intense brilliancy, and the surface sparkled all over with shifting points of dazzling light, like 'a network of lightning,' occasioned by the jets in constant play; at the start of each the white light of the depths breaking through to the surface. A row of small basins on the southeast side of the lake were also jetting out their glowing lavas. The two smaller lakes tossed up their molten rock much like the larger, and occasionally there were sudden bursts to a height of forty or fifty feet. The broad canopy of clouds above the pit, and the amphitheater of rocks around the lower depths, were brightly illumined from the boiling lavas, while a lurid red tinged the more distant walls, and threw into varying depths of blackness the many cavernous recesses." *

From the top of the outer wall of the crater of Kilauea to the surface of the molten rock is generally rather more than a thousand feet, the inner pit being some 400 or 500 feet deep. But, as Professor Dana has shown in his exhaustive study of the volcano, these measurements and many of the details are liable to great variation; the molten rock occasionally floods the lower ledge, and even rises high up in the outer crater. But paroxysmal eruptions are rare, and generally on a small scale. Kilauea is a huge caldron of molten rock, the surface of which becomes, to a very great extent, covered with a crust during times of comparative exhaustion, from which also no large quantity of steam is discharged. Showers of dust and scoria are few; it is like the mouth of a great smelting furnace, which on rare occasions threatens to overflow, but even then in consequence of a quiet swelling up of its molten contents, rather than of the usual series of violent explosions.

Krakatoa, a volcanic island in the Straits of Sunda, supplied, a few years ago, an instance of the terrific outbreak of the volcanic forces after a long period of quiescence. The island has had a varied history, but of its earlier chapters no record has been preserved. Here, at some unknown period, a large cone, the base of which may have measured five-and-twenty miles in circumference, rose to a height, perhaps, of at least 10,000 feet. At a later period, equally unknown, an eruption, or a series of eruptions, blew away this cone,

* Professor J. D. Dana, ' Characteristics of Volcanoes," p. 68.

leaving behind only a shattered and irregular crater ring. "The great crater thus formed must have had a diameter of two or three miles, and its highest portions could have risen but a few hundreds of feet above the present level of the sea." A series of comparatively quiet eruptions must have followed, which threw up a number of small cones within this crater ring. A later stage was the build-

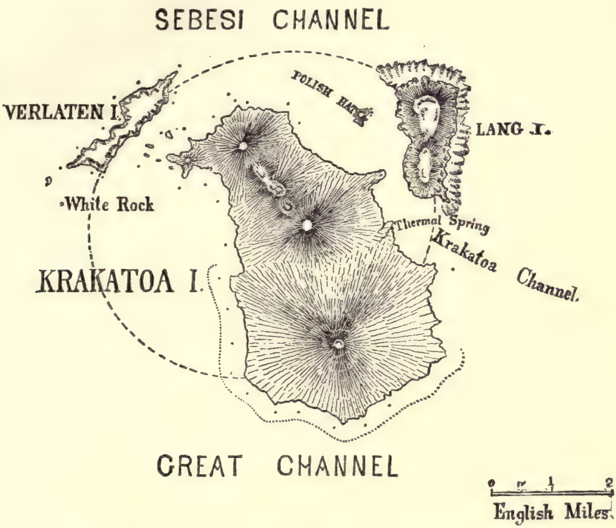


FIG. 99.—MAP OF KRAKATOA, BEFORE THE ERUPTION OF 1883.
The nearly circular line indicates roughly the old crater ring.

ing up of a cone (Rakàta) which rose on the edge of the old crater to a height of 2623 feet above the sea. An eruption occurred at Krakatoa in the year 1680; after that it remained for two centuries perfectly quiescent as a group of islands, of which three greatly exceeded the rest in size, the rim of the old ruined crater being indicated by two of these and the southern end of the largest island, while the greater part of the last was formed by the secondary cones, which, as mentioned above, had gradually accrued. A rich tropical vegetation clothed the island; hot springs alone hinted at possible dangers in the future. But in the year 1880 all the region round began to be frequently shaken by earthquakes. For more

than two years no other sign was afforded that mischief was threatening; then Sunday morning, May 20, 1883, was ushered in at Batavia and Buitenzorg * by "booming sounds like the firing of artillery." A sprinkling of ashes fell next day at the latter town, and in the evening a column of steam was seen issuing from Krakatoa. Next morning the captain of a passing vessel observed that the volcano was in active eruption, ejecting great clouds of vapor and showers of dust and pumice. The former sometimes were shot up to an estimated height of seven miles, and volcanic dust mounted so far that it drifted till it fell three hundred miles away.

For about fourteen weeks the eruption continued with varying activity, during which time several parties visited the island, and made more or less careful observations. An eruption thus commenced might reasonably have been expected to continue in a similar phase of activity, and to have ultimately died away, without any marked change, except possibly the ejection of a stream of lava. The sequel, however, was no less unexpected than terrible; but what actually did happen can only be inferred, because the island itself was uninhabited. Those nearest to the scene of the eruption, whether on land or on vessels, had enough to do to save their own lives—for many persons perished—and dense clouds of vapor and dust would have baffled the most imperturbable observer. The phase of greatest violence set in on Sunday, August 26. Soon after midday it was observed from passing ships that the island had disappeared beneath a vast cloud of black vapor, the height of which was estimated at not less than seventeen miles; frightful detonations resounded at intervals, and presently, at places full ten miles away, a rain of pumice began to fall; flashes of lightning rent the masses of vapor for miles round; the electric condition of the atmosphere was disturbed, and at a distance of fully forty miles ghostly corposants gleamed on the rigging of a vessel. Louder and louder became the explosions, blacker and blacker the cloud, yet more widespread the darkness, the storm, and the waves, till the paroxysms culminated on August 27, when four explosions of fearful intensity shook earth and sea and air, the third being "far the most violent and productive of the most widespread results."† The Titans, to use the old Greek legend, had now succeeded in breaking prison; the eruption evidently began to decline, and by

* Towns about one hundred miles away from Krakatoa.

† It occurred at 10.02 A. M. (Krakatoa time). The others were 5.30, 6.44, and at 10.52 A. M.

the 28th or 29th had practically died away, though one or two comparatively insignificant outbursts subsequently occurred.

This eruption had spread ruin and death over many leagues; it had announced itself, as will be presently seen, to places hundreds of miles distant—nay, had even put a girdle round the earth. At Krakatoa itself, when men once more reached its shores, everything was changed. About two-thirds of the main island, including all the lower part and the northern half of Rakata, were blown completely away. This marginal cone had been cut nearly in half vertically, the new cliff falling precipitously toward the center of the crater. Where land had been there was now sea, in some places more than one thousand feet deep. The remaining part of the island had

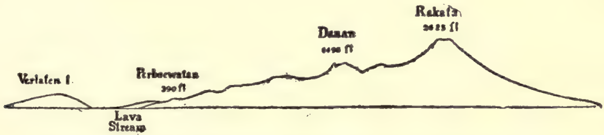


FIG. 100.—SECTION OF KRAKATOA, BEFORE THE ERUPTION OF 1883.

been somewhat increased by ejected materials. Of the other islands and islets some had disappeared, some were partially destroyed, some were enlarged by fallen *débris*, while many changes had taken place in the depth of the neighboring sea bed. Much of the ejected pumice was so full of cavities as to float upon the water. Here and there it formed great banks, which covered the sea for miles, and sometimes rose four or five feet above it, proving a serious obstacle to navigation. The enormous volumes of steam, mingled with mineral dust, which had been discharged into the upper air had darkened the sky. At Batavia, about a hundred English miles away from the volcano, it produced an effect very similar to that of one form of London fog. This began about seven in the morning of August 27, and gradually increased till, soon after ten, the light became lurid and yellow, and lamps were required in the houses; then came a downfall of rain, mingled with dust, and by about half-past eleven the town was in complete darkness. This lasted till about one o'olock, when the sky began to lighten, the rain to diminish, till about three o'clock it had ceased. At Buitenzorg a similar darkness and dust-rain occurred, but lasted there for a shorter time. The town is some twenty miles further away from Krakatoa. In many places, at distances far greater, the upper sky seemed strangely

murky, and the sun assumed a green color. These strange phenomena were traced over a broad zonal area of the globe, even as far as the Sandwich Islands, while over a yet wider area the sky after sunset was lit up by afterglows of extraordinary beauty. These were particularly conspicuous in England during the months of November and December, 1883. From a careful collation and comparison of the observations recorded it is inferred that the great dust cloud even made more than the circuit of the globe. As it spread and dispersed, the strangely tinted sun—green, blue, or copper color—was seen when its denser parts were passing; by the thinner the afterglows were produced. The finest materials probably continued to float in the atmosphere for more than a year.

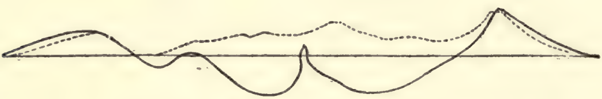


FIG. 101.—SECTION OF KRAKATOA, AFTER THE ERUPTION OF 1883.
The dotted line indicates the section of the island before.

The height to which this dust was projected at first has been calculated from various data, with the result that 121,500 feet, or nearly 25 miles, is a very probable maximum estimate, while it is not impossible that occasional fragments of larger size may have been shot up to a yet greater height.* This, however, was not all. Huge waves, originating from Krakatoa, traversed the sea, and swept the coast bordering the Straits of Sunda, destroying many villages on the low-lying shores in Java, Sumatra, and other islands. Buildings were sometimes washed away at the height of about 50 feet above sea level. The water seems occasionally to have risen still higher, and in one exceptional case to have surged up to 115 feet. At Telok Betong, in Sumatra, a ship was carried inland for quite a mile and three-quarters, and left stranded at a height of 30 feet above the sea. The disturbance of the ocean was traced — though it speedily became unimportant — even as far as Cape Horn, and, possibly, to the English Channel. The sounds of the explosion in some cases were heard more than 2000 miles away; the waves of atmospheric disturbance encircled the globe, and in one case their passage was noted seven times at

* Krakatoa Report, issued by the Royal Society, p. 379.

the same station. Still, vast as was the quantity of material ejected by Krakatoa, it was on a smaller scale, in Professor Judd's opinion, than several other outbursts which have occurred in historic times. "The great eruptions of Papandayang, in Java, in 1772, of Skaptar Jökull, in Iceland, in 1783,* and of Tomboro, in Sumbawa, in 1815, were all accompanied by the extrusion of much larger quantities of material than that thrown out of Krakatoa in 1883. The special feature of this last outburst of the volcanic forces was the excessively violent though short paroxysms with which it terminated. In the terrible character of the sudden explosions, which gave rise to such vast sea and air waves on the morning of the 27th of August, the eruption of Krakatoa appears to have no parallel among the records of volcanic activity. The peculiarity of the phenomena displayed during the eruption is, I believe, to be accounted for by the situation of the volcano, and its liability to great inrushes of the water of the sea, as the evisceration of the crater opened a way to the volcanic focus."†

Since these words were written an outbreak has occurred in Japan which, though the area of destruction was more limited, appears to have surpassed even Krakatoa in the frightful suddenness of the catastrophe. Mr. Norman,‡ who visited the spot shortly afterward, thus describes the scene of ruin. After a journey through the forests which clothed the slopes of the volcanic mountain and prevented any distant view, the travelers at last found themselves "standing upon the ragged edge of what was left of the mountain of Bandai-san, after two-thirds of it, including, of course, the summit, had been literally blown away and spread over the face of the country. . . . The original cone of the mountain had been truncated at an acute angle to its axis. . . From our very feet a precipitous mud slope falls away for half a mile or more, till it reaches the level. At our right, still below us, rises a mud wall a mile long, also sloping down to the level, and behind it is evidently the crater; . . . but before us for five miles in a straight line, and on each side nearly as far, is a sea of congealed mud, broken up into ripples and waves and great billows, and bearing upon its bosom . . . a thousand huge bowlders, weighing hundreds of tons apiece." On reaching the crater they found it a gigantic caldron, probably a mile in width, walled in with precipices of the same mud-like material; from sev-

* Of which some particulars are given below, p. 248.

† Eruption of Krakatoa, Report of Committee of Royal Society, p. 29.

‡ "The Real Japan," ch. x.

eral orifices volumes of steam were being discharged, and when the vapor cleared away for a moment glimpses of a mass of boiling mud were obtained.

Before the explosion the mountain terminated in three peaks. The highest attained an elevation of 5800 feet; the peak destroyed was the middle one, which was rather smaller than the other two. "The explosion was caused by steam; there was neither fire nor lava of any kind. It was, in fact, nothing more nor less than a gigantic boiler explosion. The whole top and one side of Sho-Bandai-san had been blown into the air in a lateral direction, and the earth of the mountain was converted by the escaping steam, at the moment of the explosion, into boiling mud, part of which was projected into the air to fall a long distance, and then take the form of an overflowing river, which rushed with vast rapidity and covered the country from 20 to 150 feet deep. Thirty square miles of country were thus devastated."

On the slopes of the mountain and the lowlands which it overlooked were fields and villages. Many lives were lost, but from the survivors Mr. Norman gathered some information, from which an idea may be obtained of the main features of the catastrophe. This is a brief outline of his narrative: At a few minutes past eight o'clock in the morning a most awful noise was heard by the inhabitants of a village ten miles away from the summit. Some instinctively took to flight, but before a man could run a hundred and twenty yards the light of day was suddenly changed into a darkness exceeding that of midnight; a shower of blinding hot ashes and sand came pouring down; the ground was shaken with earthquakes, explosion followed explosion, the last being the most violent. Many fugitives, as well as people in the houses, were overwhelmed in the deluge of mud, but the spot where the former perished was only two hundred yards from the village. From the statements made by those who were so fortunate as to escape with their lives, and from his examination of the ground, Mr. Norman inferred that the mud must have passed six miles through the air and then have rushed along the ground for four miles, in less than five minutes, so that "millions of tons of boiling mud were hurled over the country at the rate of two miles a minute." Perhaps the velocity of the mud torrent may be slightly overestimated, but in its awful suddenness this catastrophe evidently has had few equals. Probably the cone destroyed was largely composed of rather fine ash and scoria, which was almost instantaneously converted into mud by

FIG. 102.—COTOPAXI, FROM SAN ROSARIO (10,356 feet).

the condensing steam and the boiling water ejected. The quantity of water thus discharged must have been enormous.

Two episodes in the history of Cotopaxi illustrate rather different phases of volcanic activity; each is described in Mr. Whymper's great book on the Ecuadorian Andes,* and of the second he was an eyewitness. Cotopaxi is situated about thirty geographical miles southeast of Quito. Its crater rim is about 19,600 feet above the sea, for it is the highest active volcano in the world. Steam is constantly discharged from its crater, with occasional slight explosions which puff up larger jets; volleys of dust occur at rather frequent intervals. Mr. Whymper, however, was able, not only to pass a night on the cone just below the summit, but also to look into the crater. This is what he saw: "An amphitheater 2300 feet in diameter from north to south, and 1650 feet across from east to west, with a rugged and irregular crest, notched and cracked, surrounded by cliffs, by perpendicular, and even overhanging, precipices, mixed with steep slopes—some bearing snow, and others apparently incrusted with sulphur. Cavernous recesses belched forth smoke; the sides of cracks and chasms, no more than halfway down, shone with ruddy light; and so it continued on all sides right down to the bottom, precipice alternating with slope, and the fiery fissures becoming more numerous as the bottom was approached. At the bottom, probably 1200 feet below us, and toward the center, there was a rudely circular spot, about one-tenth of the diameter of the crater, the pipe of the volcano, its channel of communication with lower regions, filled with incandescent, if not molten, lava, glowing and burning; with flames traveling to and fro over its surface, and scintillations scattering as from a wood fire; lighted by tongues of flickering flame, which issued from the cracks in the surrounding slopes. At intervals of about half an hour the volcano regularly blew off steam. It arose in jets with great violence from the bottom of the crater, and boiled over the lip, continually enveloping us. The noise on these occasions resembled that which we hear when a large ocean steamer is blowing off steam."

But at any moment Cotopaxi may pass into a more violent phase of activity. One of these occurred in 1877. First a great column of dust was ejected, followed next day by a second mass, which drifted high in air above Quito, so that midday was dark as night. The next morning the summit of the volcano was clear, but about

* "Travels in the Great Andes of the Equator," ch. vi., etc.

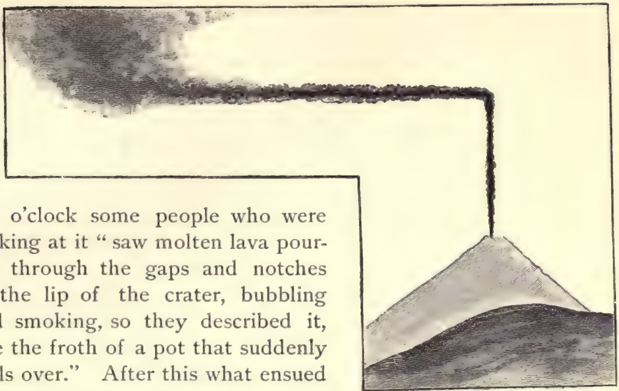


FIG. 103.—DUST CLOUD FROM COTOPAXI

ten o'clock some people who were looking at it "saw molten lava pouring through the gaps and notches in the lip of the crater, bubbling and smoking, so they described it, like the froth of a pot that suddenly boils over." After this what ensued upon the mountain no man could see, for in a few minutes the whole of it was enveloped in smoke and steam, and became invisible, "but out of the darkness a moaning noise arose, which grew into a roar, and a deluge of water, blocks of ice, mud, and rock rushed down, sweeping away everything that lay in its course, and leaving a desert in its rear." The molten matter, as Mr. Whymper points out, which overflowed from the crater, and fell in streams or cascades upon the surrounding slopes of snow and ice, must often have been sent flying into the air in shattered fragments and splashes by the sudden development of steam, and "portions of the glaciers, uncemented from their attachments by the enormous augmentation of heat, slipped away bodily, and partly rolling, partly borne by the growing floods, arrived at the bottom a mass of shattered blocks."

The other episode illustrates a milder phase of the mountain's activity. Mr. Whymper was making his second ascent of Chimborazo. The sky was bright, and the cone of Cotopaxi, sixty miles away, stood up clear in the dawning light. The great volcano was unusually tranquil, not a sign of smoke rose from its crater. "At 5.40 A. M. two puffs of steam were emitted, and then there was a pause. At 5.45 a column of inky blackness began to issue, and went up straight into the air with such prodigious velocity that in less than a minute it had risen 20,000 feet above the rim of the crater." At this height it appeared to be caught by a powerful current of air from the east, and was "rapidly borne toward the

Pacific; remaining intensely black, seeming to spread very slightly"; then it was caught by another current from the north, and drifted toward Chimborazo, spreading out rapidly. When the party reached the summit, though the cloud was then hovering overhead, the snows were clean, but about ten minutes afterward the dust began to fall, and in the course of an hour gave the white dome the aspect of a plowed field. In Mr. Whymper's words: "It filled our eyes and nostrils, rendered eating and drinking im-

FIG. 104.—VESUVIUS, FROM THE BAY OF NAPLES.

possible, and at last reduced us to breathing through handkerchiefs."* The dust had occupied some 7½ hours on its aërial journey.

The history of Vesuvius, more notably in some ways than that of Krakatoa, affords an instance of long quiescence followed by a sudden and destructive awakening. The mountain, about nineteen centuries since, exhibited an outline widely different from its present one. It terminated in a broad crater, inclosed by steep walls, comparable with that of Astroni,† but only about 500 feet lower than the height of the present summit. Scoria and lava indicated the origin of this huge natural amphitheater; but not so

* The dust consists of fragments of transparent glass and minerals (felspar and augite), with occasional bits of dark scoria. Many of these range from .003 to .004 of an inch; from this they go to the finest dust; larger fragments are rare, .01 being about the maximum size.—"Proc. Royal Soc.," xxxvii. p. 123.

† Probably it was about a mile in diameter.—Phillips, "Vesuvius," p. 176.

much as a jet of steam or spring of boiling mud issued from any fissure to intimate, as at the Solfatara, that mischief might be still a-brewing. The volcanic energy appeared to have been completely exhausted; the floor of the crater was overgrown with dense vegetation, its walls were festooned by wild vines. This period of quiescence continued for one knows not how many centuries. The memory of a volcanic outburst from Vesuvius, if it had not totally faded away, was only preserved as a dim and uncertain tradition.

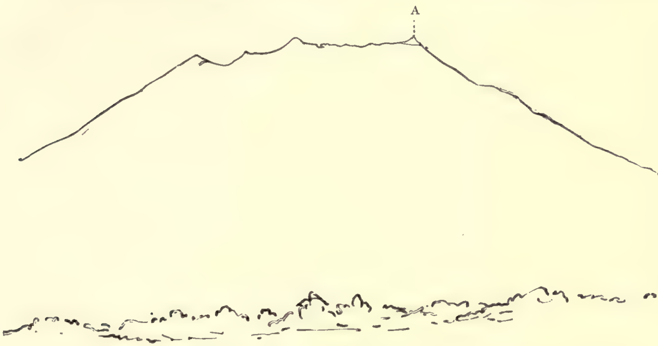


FIG. 105.—OUTLINE OF MONTE SOMMA.

This outline, sketched from the north, shows the present rim of Monte Somma and the probable shape of Vesuvius prior to A.D. 79. The cone is just visible on the spot marked A.

Then the district began to be shaken by earthquakes; for sixteen years these continued, till at last, in the year 79 A. D., on the night of August 24, they became so violent that the whole country seemed "to reel and totter." Next day, soon after noon, a huge black cloud uprose from the crater of Vesuvius. An eyewitness* compares its shape to a stone-pine, for, as he said, "it shot up to a great height in the form of a trunk, which extended itself at the top into a sort of branches. . . It appeared sometimes bright, sometimes dark and spotted, as it was more or less impregnated with earth and cinders." Presently a continuous shower of dust and ash and blocks of stone began to fall over all the country round. As night came on, the darkness was illumined with the gleam of lightning and the glare of the volcano, while the air quivered with the reports of explosions, the sea was strangely agitated, and the ground shuddered with earthquake shocks. The eruption seems to have

* The younger Pliny—quoted by Professor Phillips, "Vesuvius," p. 15.

continued in full violence for at least another day, but after that it subsided. It had wrought no small change in the mountain; half the old crater wall had been blown away and had been strewn in fragments over the slopes and lowlands all around; the remnant still encircles the northern side of the present cone, and bears the name of Monte Somma. As at that time probably a central cone had not been formed, the ruined walls would overhang a bowl-like gulf. Herculaneum, Stabiæ, and Pompeii had disappeared, the first beneath a thick mass of mud, the last under a cloak of scoria; to beyond Capo di Miseno, fifteen miles away from the crater, the whole country "was covered with white ashes as with a deep snow."

Since then the volcano has been often active, but for nearly sixteen centuries its eruptions, though not unfrequent, appear generally not to have been violent. So far as can be inferred from a rather confused account written early in the seventeenth century, a central cone had not yet been thrown up. But in 1631 another outburst occurred, only less destructive than that of 79. As before, large quantities of scoria were discharged, but on this occasion streams of lava poured down the flanks of the mountain, and reached the sea "at twelve or thirteen points." By these Resina, Granatello, and Torre del Greco were partly destroyed, and the loss of life is put as high as 18,000. Since then Vesuvius has seldom rested. A central cone seems to have been thrown up by the last-named eruption; this has been augmented, truncated, and built up again, so that for some two centuries the aspect of the mountain has not been materially changed. Vesuvius thus affords an example of a volcano, comparatively insulated in position, dominating the country round, like Etna or Teneriffe, which remained quiescent for an unknown number of centuries, then woke up, truly like a giant refreshed, to a new phase of destructive activity.

Submarine volcanic eruptions, for various obvious reasons, are more seldom observed, and less perfectly recorded. But the well-known case of Graham Island may be quoted as an example which, no doubt, is not very exceptional. The site of Graham Island was about 30 miles S.W. of Sciacca, in Sicily, and 33 miles N.E. of the island of Pantellaria.* The general depth of the water hereabouts, prior to 1831, was rather more than a hundred fathoms. "On June 28, about a fortnight before the eruption was visible, Sir Pulteney Malcolm, in passing over the spot in his ship, felt the shocks of an earth-

* Lyell, "Principles of Geology," ch. xxvii.

quake, as if he had struck on a sand bank." The adjoining coast of Sicily was also disturbed. Nearly a fortnight later the captain of a Sicilian vessel reported that he had observed in passing the water spouting up to a height of 60 feet, followed by a dense cloud of steam, which rose 1800 feet above the sea. On July 18 he passed this spot as he returned, and found there an "island 12 feet high, with a crater in its center, ejecting volcanic matter and immense columns of vapor, the sea around being covered with floating cinders and dead fish. The scoriæ were of a chocolate color, and the water which boiled in the circular basin was of a dingy red." The eruption continued with great violence to the end of the same month, at which time the island was visited by more than one person. "It was then from 50 to 90 feet in height, and three-quarters of a mile in circumference. By August 4 it became, according to some accounts, about 200 feet high, and 3 miles in circumference; after which it began to diminish in size by the action of the waves, and was only 2 miles round on August 25; and on September 3, when it was carefully examined by Captain Wodehouse, only three-fifths of a mile in circumference, its greatest height being then 107 feet. At this time the crater was about 780 feet in circumference." The island is described as consisting entirely of scoriæ and pumiceous materials, except for a few fragments of dolomitic limestone, which also had been ejected, hardly anything exceeding a foot in diameter. During the month of August the water had been seen to boil up, and a column of steam to be ejected, on the S.W. side of the island, as if a second and lateral vent had opened out in the new volcano. By the month of October the island had been almost washed away, and not long after that it disappeared; but the site was marked by a dangerous reef, oval in form, and about three-fifths of a mile in extent. "In the center was a black rock, of the diameter of about 26 fathoms from 9 to 11 feet under water, and round the rock were banks of black volcanic stones and loose sand. At a distance of 60 fathoms from this central mass the depth increased rapidly. There was also a second shoal at the distance of 450 feet S.W. of the great reef, with 15 feet of water over it, also composed of rock, surrounded by deep sea. We can scarcely doubt that the rock in the middle of the larger reef is solid lava, and that the second shoal marks the site of the submarine eruption observed in August, 1831, to the S.W. of the island." As Sir C. Lyell observes, although no lava appears to have risen up above the level of the waves, yet molten rock may

have flowed from the flank or base of the cone, and spread out in a broad sheet over the bottom of the sea.

Thus Graham Island indicates—and the example is only one of a group—how the continuity of submarine deposits, whether sands or clays or limestones, may be suddenly interrupted by the incoming of beds of volcanic ashes, and even by flows of lava. Instances of this not unfrequently occur. For example, in the limestone district of Derbyshire we find that this rock in one place changes abruptly in an upward direction into an ashy deposit, in which marine shells occur, indicating that the denizens of the sea bed probably suffered the same fate as the inhabitants of Pompeii; in another place the limestone is covered by a chocolate-colored volcanic mud, and over each of these deposits comes a sheet of lava, which obviously must have flowed on the old sea bed. The very summit of Snowdon itself bears testimony to a similar condition of things, for it is formed of an ashy rock which is crowded with the impressions of seashells.

The instances of volcanic eruptions described above indicate that they are accompanied by explosive phenomena, often of tremendous violence, and that the result of these not seldom is destructive. It is also constructive. In many cases the cone itself obviously is built up by the ejected material; the whole mound of Monte Nuovo and the central hill of Vesuvius have both been formed during the last few centuries. By the examination even of volcanoes still active we are led to the conclusion that they are at least very largely the product of erupted material, and this is strengthened, as will presently be seen, by the study of the structure of those which have become extinct. But before proceeding to this anatomical investigation, as it may be called, we may do well to notice one or two phenomena connected, more especially, with the discharge of lava. This, however, does not always occur. Craters there are, like some of those in the volcanic district of the Eifel, from which no lava has ever flowed, and sometimes no large quantity of ash and scoria has been ejected. Such are the craters—now occupied by small lakes—of the Gemunder Maar or the Weinfelder Maar, near Daun, or the Pulver Maar, near Gillenfeld, where in the discharged materials bits of slate (the country rock) are almost as abundant as scoria. The vapors imprisoned beneath the surface appear to have blown a small hole in the earth's crust, from which a few showers of volcanic dust and ash, mingled with shattered sedimentary rock, have been thrown out. Evidently not one of these craters can have remained active

for any long time, for otherwise a larger amount of material would have been ejected; they were very probably, like Monte Nuovo, the outcome of a single eruption. But lava, as a general rule, is discharged, in the course of an eruption, usually rather late in its history. Sometimes, as was described in the case of Cotopaxi, and has happened more than once in Vesuvius, the lava wells up in the crater, like water from a spring, and overflows the rim, streaming down the outer slopes in glowing torrents, or occasionally in one unbroken sheet of molten rock. More often the walls of the crater are ruptured by the pressure of the rising mass, and the incandescent material rushes out from the fissure. Not less frequently cracks open out in the mountain itself, through which the lava escapes, as by a lateral passage, before reaching the bottom of the crater, and issues on the slopes some distance below the base of the actual cone. Indications of the cracked and often tottering condition of many volcanic mountains are afforded by the parasitic cones, which are frequently numerous. So many have been counted on Etna that, on a small scale model, the volcano seems to be suffering from a bad outbreak of boils. On Vesuvius an interesting example of one of these emissaries of a lava flow can be readily examined. The outbreak occurred during the eruption of 1861, on the southern side of the mountain, some considerable distance below the base of the actual cone. The slope is interrupted by a shallow trench, hardly deep enough to be called a glen, which is terminated at its upper end by a cliff perhaps fifty feet high. This affords a section of bedded volcanic materials of a yellowish-gray color—finer and more regularly stratified in the upper part, coarser and more irregular in the lower. The cliff is split by a crack, running vertically upward, and narrowing in that direction, till it is lost to sight in the finer and more incoherent material.

At the bottom, where it is widest, the surface of a wedge-like mass of lava is first exposed, a mere chine of rough rock. The bed of the gully, a short distance further down, is choked by a low monticule of scoria, forming a double crater, the upper and larger basin, which is in shape an oval, being about sixty yards long and thirty wide; from this a line of eight other small and low cones can be followed down the hillside, the lava flow broadening out from below the base of the last. These craters evidently mark the course of a fissure from which the lava has issued and at close intervals has "blown off steam" as the pressure was removed from which it had suffered during its subterranean course.

One of the most remarkable instances on record of the underground passage of lava happened in the Sandwich Islands in the year 1840* in connection with a threatened eruption of Kilauea. In the earlier part of the summer the molten lava had welled up high in the crater, but about the month of June it came to a standstill, after which its surface began to sink. The cause of this change was speedily made apparent. Six miles away, at the bottom of an old wooded crater called Arare a glowing mass became visible, which, however, did not overflow or even fill up the crater. Next, a mile or two down the slope, a stream of lava broke forth from the ground, and, spreading out as it flowed, covered an area of about fifty acres. After this, yet some miles lower down, the lava again appeared at the bottom of another old wooded crater, which it filled up, but without further overflow. Lastly, at a distance of twenty-seven miles from Kilauea, and 1244 feet above the sea, the glowing stream finally emerged from the earth, and ran for twelve miles further, till it poured down a cliff fifty feet high, and its further course was arrested by the ocean. As we cannot suppose the existence of a line of caves or subterranean channels—for by what means could they be excavated or even kept open?—this mass of molten material must have forced its way under ground from some rent which had been made in the pipe leading to the crater of Kilauea. As the lava was sufficiently liquid on emerging from a subterranean journey of twenty-seven miles to run for twelve more in the open air, it must have been raised originally to a temperature far above the melting point of the material. Probably the three minor outbreaks which marked the line of its passage underground were not on the actual course of the main stream, but indicated the ends of small offshoots from it which had forced their way into lateral fissures along lines of weakness.

As lava flows onward its surface is overhung by a cloud of steam, disengaged from the glowing mass. The discharge sometimes continues for weeks after motion has ceased and the mass has apparently cooled. This, however, is generally a rather slow process. Lava is a very bad conductor, so that when a crust has once formed on its surface heat escapes from the interior very gradually. Even after a lapse of three or four years a lava stream may often be seen

* Sir C. Lyell, "Elements of Geology," ch. xxix.; J. D. Dana, "Characteristics of Volcanoes," p. 61.

A LAVA-STREAM FLOWING INTO A LAKE, HAWAII

to steam in many places after a shower of rain, showing that the lower part of the mass is still warm.

Hardly anything is known as to the temperature of lavas when they emerge from a volcano, but this generally must be considerably above the actual melting point of the rock. Even as to that our information is still very imperfect. Obviously its exact value must depend, in the first instance, on the chemical composition of the mass. But it is also affected, even in the same rock, by the quantity of water present; for this, as will be more fully indicated in a later chapter, has a marked effect in facilitating fusion. At Vesuvius, on one occasion, the temperature of lava still in motion was found to be as low as 1228° F., while a piece of silver wire was quickly melted on another occasion, and copper on a third. These facts signify temperatures exceeding 1800° F. and 2204° F. respectively. Probably, as a rough estimate, the temperature of lava when first emitted, as a rule, is not below 2000° F.*

The aspect of a lava stream varies much, in accordance, partly, with its chemical composition. It may be glassy, slaggy, or "stony"; it may be smooth or rough in texture; it may be solid or full of cavities, which may be small or comparatively large, in shape regular or comparatively irregular. In color it may be light grayish, yellowish, or greenish—or dark to almost black. Lavas allied to basalt are perhaps, on the whole, the commoner. These also differ much in appearance, though not in color. The surface of some streams is comparatively smooth and slaggy-looking, wrinkled and ropy, all in folds and rolls and coils, as if from the slow flowing of a viscous mass; while the surface of others is rough and jagged and extremely irregular, like a heap of cinders or the top of a wall built with "clinkers." Both kinds are common in the Sandwich Islands, where they have been distinguished by native names. Both may have been ejected by the same volcano at different dates, as may be seen on Vesuvius.

More than one of the instances of volcanic activity described above makes it clear that the materials ejected from a volcanic orifice build up the cone with its crater. Supposing no destructive effects from explosions of more than usual violence, part of each volley of scoria, after a path of greater or less length through the air, falls down on the outer slope of the heap already accumulated.

* The melting point of pure iron is estimated at about 1600° F., of silver about 1873° F., of gold 2015° F. The lava in the crater of Kilauea is often observed to be at a white heat, which indicates a temperature of about 2400° F.

Some fragments lie where they have dropped, some half-molten splashes may even aid in cementing the mass together, but other fragments roll for some distance down the slope of the cone, becoming rudely sorted out by size and weight, as when gravel is "tipped" down a bank. Thus the cone assumes a roughly stratified structure, and as it increases in dimensions, vertically and laterally, the slope of its exterior probably diminishes. The mass may be strengthened by the occasional overflow of lava from the crater, or from rifts in its side. In the latter the molten matter solidifies, forming what are called dykes, and helps in binding the whole together. Cones formed entirely of solid lava are not unknown, but these are generally small and steep-sided, and have been built by up-squirted stuff as vapor is escaping from the surface of a large stream of very liquid lava.

That a volcano is reared practically by one architect, that the whole cone and the mountain proper are formed by the ejected material, is now generally admitted. But this opinion was not always favorably regarded. Before the days of Scrope and Lyell the ejected materials were generally supposed to play a subordinate part, and a volcanic mountain was held to be largely due to the upheaval of the strata of the earth's crust in a conical form around the orifice. In this hypothesis obvious difficulties existed, such as that of understanding how beds thus uplifted could maintain their position as soon as the imprisoned vapors and lava had escaped from beneath ; but as a lengthy discussion of an idea which always owed more to fancy than to fact is unnecessary at the present day, it may suffice to give some account of dissected volcanoes in order to show that no such hypothesis is in accord with the facts observed. "Subjects," to use the technical term, prepared by Nature to illustrate the pathology of volcanoes can be found in some parts of the British Isles, or at no very great distance from their shores. Though no craters remain in the former region, these are abundant in the Eifel, or still better in Auvergne, where their condition is so perfect that it is sometimes hard to believe that eruptions have not occurred within the period over which history extends.* The vent, indeed, is tightly sealed ; grass

* Passages occur in the writings of Sidonius Apollinaris, Bishop of Clermont *circa* 460 A. D., and Alcimus Avitus, Archbishop of Vienne, born about the middle of the same century, which, if not merely bombast, imply that there were some eruptions, possibly but slight, in Central France about that time. Most of the craters, however, are undoubtedly older than the historic ages. (See *Geological Magazine*, 1865, p. 241.)

covers the slopes of cone and bowl; cattle graze peacefully, as the scoria still sometimes grates beneath their tread, on the spots where glowing ashes once fell like rain, or clamber over the rugged surface of the lava streams to seek the herbage which now sprouts from its cracks. Here and there, as in the Puy de las Solas and Puy de

FIG. 106.—BREACHED CRATERS, AUVERGNE.

la Vache, the cinder cones have been burst by the pressure of the lava swelling up within so as to afford opportunities of ascertaining their structure. In many other places partially destroyed cones are common. Always they consist of ejected materials, and exhibit a rude stratification, as above described.* In a more advanced state of ruin the crater has entirely disappeared, and the cone has been reduced to a stump, consisting often of a central plug of lava, which

* Occasionally the beds in the inner part of the crater dip inward or in the reverse direction to those which make up the greater part of the cone. These would be formed as the eruption was subsiding, and the explosive force no longer sufficed to heave the materials beyond the rim of the crater.

now forms the culminating point of the hill, while masses of scoria still cling to its flanks, sometimes in considerable quantities, sometimes merely in fragmental patches. This, in the opinion of some geologists, is the history of Arthur's Seat, near Edinburgh. It is generally admitted to be true of many "laws" in Scotland, and of not a few hills in Auvergne, the Eifel and other old volcanic districts; also in the central valley of Scotland many volcanic "necks" may be seen—often on quite a small scale—representing a still more advanced stage of dissection. Sometimes the continuity of the stratified beds in the face of a cliff is sharply interrupted by a dark mass which, on closer examination, proves to be formed of volcanic material, mingled occasionally with fragments of sedimentary rock, or seamed with a dyke. Sometimes on the seashore a similar dark mass, more or less circular in form, interrupts, like an island, the uniform lines of the outcropping edges of the strata, and is found to have a similar composition. The one is a vertical, the other is a horizontal section of a volcanic neck. The Fifeshire coast affords many examples, in the neighborhood of Burntisland, or between Elie and St. Monance. The noted Rock* and Spindle, near St. Andrews, is a fragment of a volcanic neck, the former being a mass of volcanic agglomerate, the latter a section of an intrusive mass of basalt, more or less cylindrical in shape, which has set up a radiating columnar structure. So, as the geologist's eye becomes trained, he is able to pass onward from these more conspicuous and obvious examples to discover in the granitic hills of Mull, and the dark masses which form the wild crags of "the Cuchullins," in Skye, proofs that these are the last remnants of volcanic mountains which in their day—and that is comparatively a late one in the long annals of geology—were no unworthy rivals of Etna or of Teneriffe; nay, even Ben Nevis itself may be only the time-worn fragment of a volcano which became extinct at a far earlier epoch.

In no case can evidence be obtained which lends any real support to the notion that the upheaval of stratified rock has played an important part in the formation of a volcanic mountain. So far from this, it all tends rather to the contrary opinion, for the strata are not seldom found to be somewhat bent in a downward direction near to a volcanic orifice. This might be expected as the result of

* "Rock" is not used in its geological or popular sense, but in an old one, meaning a distaff.

removing so much material from beneath the crust and piling the same upon it over a limited area—not to mention the effect which would be produced by the shrinking of the once heated mass below as it gradually cooled. So even such lofty volcanic mountains as Etna and Teneriffe, as Loa and Kea, in the Sandwich Islands, are wholly formed of the materials ejected from orifices which at first were but little above the sea level, and in some cases probably were actually a considerable distance below it.

It must not be supposed that the whole of a mountain apparently volcanic is invariably constituted of ejected materials. Orifices may open on a plateau or on some part of mountain masses which are already of considerable elevation. This, indeed, is true of many, if not most, of the highest volcanoes; no inconsiderable proportion—perhaps as much as two-fifths, possibly more—of such summits as Elbruz and Kazbek in the Caucasus, or of the Andes of the equator, must consist of rocks, whether sedimentary or crystalline, which belong to an epoch long prior to the volcanic explosions. Still, every one of the actual peaks about Quito, peaks rising from about six thousand to eleven thousand feet above the upland mass which may be regarded as their common foundation, consists, so far as known, of volcanic materials.

Facts such as these give some idea of the enormous quantity of this ejected material. The suggestion has been sometimes made that, as the world is waxing old and its energy is being dissipated, the volcanic phenomena of the present era are feeble and puny compared with the outbreaks of its hot and lusty youth. This should be so, and, no doubt, in a sense is so; but, as Lord Kelvin has pointed out, the very fact that a gradual loss of heat results in a thickening of the crust may cause the explosive phenomena to be, indeed, more unfrequent and localized, but more violent when they do occur—may produce, in short, the effect of screwing down a safety valve. So that the masses of material ejected during late geologic or even historic times may be quite comparable with those which were discharged in much earlier ages, after every allowance has been made for what may have been removed by denudation. The Sandwich Islands consist almost wholly of volcanic material, the amount of coral reef or rock composed of organic *débris* being comparatively trifling. They have been built up, certainly from sea level, probably from greatly below it—for in that part of the ocean the general depth of its floor is at least 2000 fathoms—to heights in some cases of not less than the same amount above

its surface. They are, in fact, as Professor Dana states, "a line of great volcanic mountains. Fifteen volcanoes of the first class have existed, and have been in brilliant action along the line. All but three are now extinct, and these three are on the easternmost and largest island of the group—Hawaii. Hawaii is made out of five of the volcanic mountains," two—Kea, 13,805 feet, and Loa, 13,675 feet—being much higher than the rest (Fig. 98). Its area is 3950 square miles, and the whole area of the group is 6040 square miles.* Doubtless this piling up of mountains of scoria and lava—though in all probability the beginning of the island was, geologically speaking, a comparatively late event—has occupied many thousands of years. Still the stream already mentioned, which escaped from the one crater of Kilauea, and had a total course of 39 miles, though a mere driblet compared with the mass of Hawaii, would be regarded as an important lava current at any geological epoch. So, too, the great basalt sheets which in Tertiary ages welled up from countless fissures in Idaho, or those which can be traced—though now but as fragments—along the west coast of Scotland from the North of Skye even across the sea to Antrim, are comparable with any which have been discovered among the older rocks. To conclude with a single example, and that barely more than a century old—Skaptar Jökull, in Iceland. This volcano entered upon a stage of violent eruption in the summer of 1783. Besides the usual discharges of steam, scoria, and similar materials, it emitted two enormous masses of lava. The one was 45 miles, the other 50 miles long. They flowed in opposite directions along valleys, and rose up in the narrower defiles to a height of about 600 feet, but attained commonly a thickness of 100 feet; in the more open country they broadened out, in the one case, to about 7, in the other to even as much as 15 miles across. Had the volcano arisen on the site of the city of London, and the structure of the country permitted, the one stream would have reached to beyond Hassocks, and the other almost to Cambridge. Probably the quantity of lava ejected would have sufficed to bury the whole county of Norfolk beneath a layer 100 yards thick.

It will naturally be asked, What is the cause of a volcanic eruption? The facts cited above clearly indicate that steam generally issues from a volcano, and is discharged in vast quantities during its

*See Professor J. D. Dana's "Characteristics of Volcanoes," p. 25, and Captain C. E. Dutton's "Hawaiian Volcanoes," Fourth Annual Report of the United States Geological Survey, p. 81.

paroxysmal phases. After the eruption of Etna, in 1863, Professor Fouqué attempted to estimate the amount of water which had been ejected in the form of steam, and arrived at the conclusion that about 79 cubic yards of water were thus discharged by each explosion. As these occurred on an average once in four minutes for a hundred days, the total quantity of water emitted would amount to 2,829,600 cubic yards, enough to form a lake about 4000 yards long, 700 wide, and 10 deep. The calculation was founded only on the steam discharged from Monte Frumento, an important lateral cone, and the site of the actual eruption. The central cone also ejected considerable quantities, of which, however, no estimate was attempted.

The explosive force of steam is well known to all; boilers sometimes give an experimental demonstration, with melancholy results. Even the British householder and his careless servants occasionally receive an impressive object lesson when the kitchen boiler has been allowed to run dry and water has been suddenly let in upon its red-hot plates. But a lava stream, as it was flowing down the slopes of Etna in 1843, once gave a demonstration on a grander and more disastrous scale. "A crowd of spectators, who had come from the town (Bronte), were examining at a distance the threatening mass, the peasants were cutting down the trees in their fields, others were carrying off in haste the goods from their cottages, when suddenly the extremity of the flow was seen to swell up, like an enormous blister, and then to burst, darting forth in every direction clouds of steam and volleys of burning stones. Everything was destroyed by this terrible explosion—trees, houses, and cultivated ground—and it is said that sixty-nine persons, who were knocked down by the concussion, perished immediately or in the space of a few hours. This disaster was occasioned by the negligence of an agriculturist, who had not emptied the reservoir on his farm; the water, being suddenly converted into steam, had caused the lava to explode with all the force of gunpowder." *

Geysers also strongly support the idea that steam is an important, if not the main, agent in the characteristic phenomena of a volcanic eruption. A geyser, as already said, may be termed a water volcano, for it ejects this instead of scoria and lava. It consists of a cone or mound, which usually rises a few feet above the general surface of the ground; in the middle of this is a crater, from the bottom of

* Réclus, "The Earth," ch. lxvii.

which a pipe leads down into the earth. Here also the cone is built up by the geyser itself; a certain amount of silica is dissolved in the boiling water, and as the later rapidly cools when it falls in showers round about the orifice, the mineral is precipitated. Commonly the basin of the geyser is full of clear water, and a little steam curls up quickly from its surface, but now and again an eruption takes place, sometimes at intervals singularly regular—as in the case of Old Faithful at the Yellowstone Park—but, as with the Great Geyser of Iceland, more often at irregular intervals. Occasionally, indeed, artificial means can be employed to produce an eruption; this is the case with one of the smaller geysers in the Icelandic region, which is called Strokr, or the Churn. A barrow load of sods is thrown into the throat of the geyser; this not unnaturally turns its stomach, and has all the effect of an emetic. The sensitiveness of Strokr is due to its peculiar form. "The bore is 8 feet in diameter at the top, and 44 feet deep. Below 27 feet it contracts to 19 inches, so that the turf thrown in completely chokes it. Steam then generates; a foaming scum covers the surface of the water, and in a quarter of an hour it surges up the pipe, allowing one ample time for escape to the edge of the saucer. The fountain then begins playing, sending its bundles of jets rather higher than those of the Great Geyser, flinging up the clods of turf, which have been its obstruction, like a number of rockets. This magnificent display continues for a quarter of an hour or twenty minutes. The erupted water flows back into the pipe from the curved sides of the bowl. This occasions a succession of bursts, the last expiring effort, very generally, being the most magnificent. Strokr gives no warning thumps, like the Great Geyser, and there is not the same roaring of steam accompanying the outbreak of the water." The same author * thus describes an eruption of the Great Geyser, which occurred about two o'clock in the morning: "A violent concussion of the ground brought me and my companions to our feet. We rushed out of the tent in every condition of *déshabille* and were in time to see Geyser put forth his full strength. Five strokes underground were the signal, then an overflow, wetting every side of the mound. Presently a dome of water rose in the center of the basin and fell again, immediately to be followed by a fresh bell, which sprang into the air full 40 feet high, accompanied by a roaring burst of steam. Instantly the fountain began to play with the utmost

* S. Baring-Gould, "Iceland: Its Scenes and Sagas," ch. xxi.

violence, a column rushed up to the height of 90 or 100 feet against the gray night sky, with mighty volumes of white steam cloud rolling about it, and swept off by the breeze to fall in torrents of hot rain. Jets and lines of water tore their way through the clouds, or leaped high above its domed mass. The earth trembled and

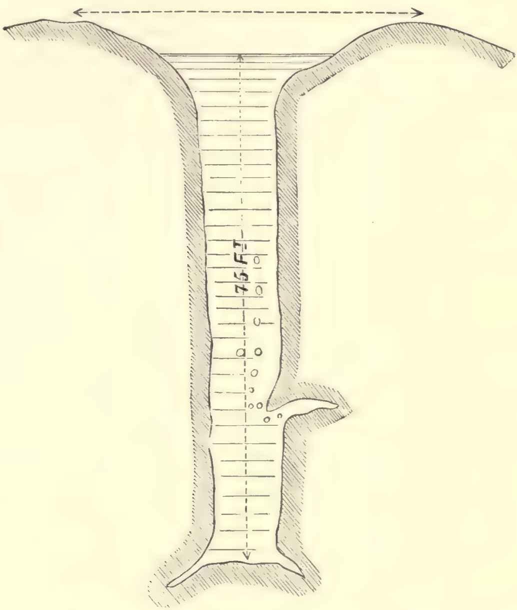


FIG. 107.—SECTION OF THE GREAT GEYSER.

throbbed during the explosion; then the column sank, started up again, dropped once more, and seemed to be sucked back into the earth. We ran to the basin, which was left dry, and looked down the bore at the water, which was bubbling at the depth of 6 feet."

In the case of Strokr the cause of the eruption seems obvious; the turf chokes up the narrow part of the pipe, the steam is prevented from escaping, until at last it removes the obstacle with explosive violence, just as a bottle of fermenting liquor, imperfectly secured, may blow out the cork and discharge some of its contents.

In the case of the Great Geyser, while it is pretty evident that steam has much to do with the eruption, the exact cause is not so clear, and several explanations have been proposed. But there can be little doubt that the right one has at last been found. Certain facts have been ascertained, as the Great Geyser has been carefully studied by successive observers, of which account must be taken in attempting any explanation. The shaft is about 75 feet in depth. Its diameter, which is about 10 feet, continues uniform to the bottom, but a sort of ledge exists on one side, at a depth of about 44 feet, which is called after its discoverer, Bunsen, the eminent philosopher. From beneath this ledge, when the tube has been emptied by an exceptionally violent series of explosions, steam has been observed to escape, so that it must signify the mouth of a lateral orifice. This roughly indicates the lower limit of the explosive phenomena, for if stones attached to strings of various lengths are suspended in the shaft, those above this ledge are ejected during the eruption, while those which hang down below it are not disturbed. The temperature of the water in the shaft has also been observed at different depths. Pressure, it must be remembered, affects the boiling point of water, so that even if ebullition took place on the surface of the basin, this would not be the case in the shaft unless the water was raised to a higher temperature, the amount of which would depend on the depth. At the bottom of the shaft the water would not boil till it was raised to a temperature of nearly 257° instead of 212° F. The temperature at the top of the shaft is 186° F.; it is found to increase in proportion to the depth from the surface, but it nowhere attains the boiling point for the depth. Just on the level of the ledge the difference between the actual temperature and that required for boiling is slightly less than 4° F. If, then, by any means the layer of water at this level can be suddenly lifted up only six feet, it will have reached a horizon where the boiling temperature is rather more than a degree below its own temperature. A sudden and explosive development of steam will be the result, which will raise the contents of the upper part of the pipe and discharge some of them into the air. More water is then brought to a level where it can flash into steam, and the discharge has helped in diminishing pressure, so that explosions yet more violent occur. Like the shot in a gun when the powder is ignited, the whole "charge" of water is shot up from this huge blunderbuss, but it drops back quickly into the barrel; steam is thus imprisoned; there is a recoil as of a spring, and a new discharge. So the geyser plays

till the steam has managed to escape and much of the water has been spilt. Observers of a geyser in eruption have frequently recorded that a loud rush of steam is the signal that the display is at an end.

The geysers doubtless exhibit local variations, but the story of this one seems to leave no room for doubt, and the interpretation proposed to explain the facts has been verified by experiment; for Professor Tyndall constructed in his laboratory at the Royal Institute a working model of the Great Geyser, and produced an eruption by filling with hot embers a small chafing dish constructed round the middle part of the tube.* We seem, then, justified in adopting this conclusion—that as an eruption of water in the case of the Great Geyser is produced by an accumulation of steam, which leads to a further explosive development of vapor, so in regard to ordinary volcanoes, whatever kind of materials may be ejected, the actual eruption, the explosive phenomena, are due to the action of steam. Gases of various kinds may contribute to the general result, but there can be no doubt that the vapor of water plays the largest part.

The geographical relations of volcanoes are also significant. Some, it is true, at first sight appear disconnected in position and sporadic in distribution, but even these in many cases prove, on closer study, to be merely the survivors of a much more numerous band of volcanoes, for they are linked together by ruined cones. Thus Etna, Vesuvius, and the Lipari Islands are the last remains of a much more extensive series of Italian volcanoes. Those of the Greek Archipelago seem to form a separate Mediterranean group. In the Atlantic the number of active volcanoes is small, but Iceland marks the last cluster of open vents on a long but interrupted line, of which one end may be placed on the west coast of Greenland, the other in Antrim, whither it can be traced through the Faroë Islands and along the western coast of Scotland. The Azores, Canaries, and Cape de Verde Islands mark the position of another series of craters, now almost extinct, which may be traced southward by St. Helena and Tristan d'Acunha. Rodriguez, Mauritius, and Bourbon on the eastern side of Africa indicate another volcanic chain somewhat similar in situation; and on the mainland, east and west, volcanoes which have now become extinct and sometimes are in ruins, such as the Camaroons or Kilimanjaro, occasionally occur.

* The model is described in his book entitled "Heat, a Mode of Motion," ch. iv.

Not till the eastern side of the Indian Ocean and the Pacific is approached do volcanic mountains become comparatively common or is their connection strongly marked. With the Andaman Islands, in the Bay of Bengal, begins a linear series of volcanoes which passes through Sumatra, Java, and the smaller islands east of the latter to the western end of New Guinea. Here a great spur is thrown off to the north as the volcanic belt continues on through that island and sweeps by the Solomon and other small islands to New Zealand. The spur just mentioned takes a northwestward course to the Philippine Islands, but the volcanoes in Borneo on the one hand, and the Marianne Islands on the other, indicate that in this region a very large area of the earth's crust is subject to these disturbances. From the north end of the Philippines a linear arrangement of the vents again becomes more or less conspicuous. They run almost parallel with the China coast to Japan, and are continued through the Kurile Islands to the long peninsula of Kamtschatka, on which they are studded. The end of the continent of Asia only slightly interrupts the continuity of this chain of furnaces; it begins again in the Aleutian Islands, reaches the American mainland, and runs on through Alaska. In the northern part of the American continent active volcanoes become for a time few and far between, but at no distant epoch, geologically speaking, they were scattered along the mountains on the western border of the continent, almost from one end to the other. Among these extinct craters or ruined cones are frequent. The ranges in the west of British Columbia, the chain of the Cascades in Oregon, the parallel ranges of the Sierre Nevada, and the Rocky Mountains are dominated by volcanoes; but only a few of these continue to eject occasionally steam and ash, such as Mount Fairweather in the extreme north, and Mount Edgecumbe on Lazarus Island, or Mount Baker, Mount Renier, and Mount St. Helen's in the United States territory. Indications of eruptions comparatively recent may be traced through California and Northern Mexico, while Central Mexico is a region of active volcanoes, many of which are of a gigantic size. Hence the line of vents continues along the rapidly narrowing continent; the low isthmus of Panama is only a temporary interruption, and they break out with renewed fury in South America. The Andes, from one end of the chain to the other, culminate in volcanic cones, which are still fairly active in three distinct regions—namely, in Ecuador, Peru, and Chili. It is doubtful, indeed, whether this line of disturbance is not prolonged far to the south of the

American continent, for, nearly opposite to Cape Horn, Mounts Erebus and Terror rise like twin beacons near the margin of the Antarctic land. An offshoot from this enormous belt of fire may be traced in South America along the south shore of the Caribbean Sea to the Antilles, while in an opposite direction the sporadic groups of the Galapagos, Society, and Tonga islands may indicate the existence of a zone which bridges the Pacific and links together the two great belts which border its eastern and western shores. The Sandwich Islands volcanoes also assume a somewhat linear order, though there are difficulties in joining these on to any of the other series.

All these volcanoes, it will be observed, rise either directly from the ocean or within a moderate distance of its coasts. Nor is this all, for if a search be made for volcanoes in the interior of continents, it almost always proves fruitless. One or two vents still active are said to exist in Mongolia, but the fact is far from being well established. Demavend, at first sight, appears to be an exception, but even it is situated on the shores of the Caspian. Such a survey as that which has been briefly indicated appears to lead to two inferences—one, that volcanoes are commonly arranged in lines; the other, that when active they are generally in the neighborhood of large sheets of water.* The former fact suggests a connection between volcanic vents and lines of weakness or fracture in the earth's crust; the latter that their paroxysmal activity, perhaps even their existence, depends upon the proximity of water, so that "without water no eruption" might almost be regarded as an axiom. A corroboration of this relation is found in the fact that common salt is among the products of an eruption. In Sicily the slopes of Etna are sometimes white with a saline efflorescence, and in Iceland the salt which remains behind on Hecla, after the fallen water has evaporated, is said to be occasionally in sufficient abundance to be collected by the peasants. Moreover, it has been observed that almost all the constituents of sea-water occur in eruptive products, the bromine salts alone not yet having been detected. Diatoms also, both fresh-water and marine, have been found in volcanic ashes, and those discovered by Ehrenberg, near the Laacher See, are said to have been partially fused. To whatever cause, then, the occurrence of great masses of molten rock may be attributed—which must be presently considered—the evidence seems

* Great lakes existed in Auvergne at the time of the more important volcanic eruptions.

strong in favor of regarding eruptive phenomena as very largely due to the effects of water. But if the explosions may be attributed to the conversion of water into steam, either by contact with heated rock or by the sudden removal of pressure which retained it in a liquid condition in a molten mass, if the outward flow of the lava is due to similar but less paroxysmal action, by what cause or causes has this mass been melted? It is believed with good reason, as will be presently seen, that the temperature of the earth's interior is very high. From a short distance below the actual surface there is a gradual increase of heat in descending, so that a temperature of 2000° F. is probably reached at a depth of about twenty-two or twenty-three miles. This, as already said, is about the melting point of several kinds of rock, so that if by any means a mass could be forced up to the surface from such a depth without materially cooling, it would become liquid, even though it had previously remained, owing to the great pressure, in a solid condition. The above-named depth, however, may be regarded as a minimum, and it would often be necessary to bring up the materials from at least twenty-five or sometimes full thirty miles; so that difficulties have been felt as to the existence of a motive force which would be competent to raise materials quickly from so great a distance beneath the surface. In the hope of avoiding these, various hypotheses have been advanced to account for a development of heat at more moderate depths which would be sufficient to melt rocks already solid.

The late Sir Humphry Davy suggested that heat was developed by chemical action in the following way: He assumed that the earth's interior, within a comparatively short distance from the surface, consisted of metallic substances not yet combined with oxygen. He supposed that as water percolated downward it came into contact with this inner mass, and its oxygen entered into new combinations,* thus producing an amount of heat sufficiently great to melt the neighboring rocks. But he ultimately abandoned the hypothesis on the ground that the "flames" of a volcano, instead of being burning hydrogen gas, were only the glow of the molten rock reflected on the steam. Of late years the force of this objection has been weakened, for the flame of burning hydrogen has been not seldom observed in a volcanic eruption. The quantity, however, is not sufficient, really, to overcome the difficulty, and another one

* Oxygen also would be present in solution in the water.

has been brought forward, which is even more serious—viz., the magnitude of the mass which must be oxidized in a comparatively short time in order to develop a sufficient amount of heat. For instance, it was calculated by Professor Fouqué that the amount of heat disengaged in the eruption of Etna—which, as already mentioned, he carefully studied—would require a mass of sodium to have been oxidized which measured one hundred meters in length and breadth and seven hundred meters in height.

Some authors have considered the heat to be produced by magnetic currents. Such undoubtedly exist, but so little is known at present of either these or their effects that any appeal to them in explanation of a difficulty is like expounding a parable by a riddle, and it may be doubted whether either these currents or the local resistances to them are sufficiently strong to develop enough heat to raise the temperature of a large mass of rock by some hundreds of degrees.

Another solution of the difficulty was propounded by the late Mr. Mallet, which, however ingenious it may be as an exercise in mathematical physics, obtains very little support from any known geological facts. Assuming the earth to have been once a molten mass, and to lose heat by radiation, it would be covered, after a time, with a thick crust. As the inner part continued to cool, and so to contract, it would tend to shrink away from the crust; this accordingly would cease to be strained, and be subjected to thrusts. The amount of these can be estimated, and Mr. Mallet came to the conclusion that the pressures thus developed would be more than sufficient to crush to powder any of the rocks which enter into the composition of the earth's crust. As the latter is not of uniform strength throughout, it would yield locally, and the crushing would be sudden and restricted to comparatively limited areas. But when rock is thus crushed, heat is developed. The amount of this also can be calculated. According to Mr. Mallet, the heat which would result from crushing 1 cubic foot of ordinary rock would suffice to raise 3½ cubic feet of the same to a temperature of 2000° F.—or, in other words, to melt it. Thus, in his view, a certain portion of the heat given off by radiation is utilized in doing work in the outer crust of the earth, and is there locally reconverted. So far as he could estimate, the transformation into heat of the energy expended in crushing about 247 cubic miles of average rock, or one-quarter of the heat which the globe annually loses by radiation, would suffice to account for all its volcanic phenomena.

But this explanation, promising as it may seem, is attended with most serious difficulties. For instance, in many cases no connection can be established between a volcanic region and one where earth movements on an important scale are in process. The vents, indeed, may mark the position of a line of fracture or weakness, but this is likely to indicate strain rather than compression. It is also very doubtful whether, even in the latter case, the rock would be suddenly crushed in masses sufficiently large to produce any very material elevation of temperature. The destructive process in all probability would be, comparatively speaking, a gradual one, and the heat thus generated would be dissipated without producing any very marked effect. But in this respect it is possible to submit the hypothesis to a kind of test. It is generally admitted by geologists that many rock masses, both sedimentary and crystalline, have been subjected to great compression, by which they have been folded or cleaved, or sometimes actually crushed. Here, then, in such a region as the Alps, where it can be proved often that a granite has been converted by crushing into a kind of schist, where the whole process of mechanical change can be traced in every stage, some indications should be found of such a result as Mr. Mallet's hypothesis requires. The minutest structure of the rock in each phase can be studied under the microscope—if a bit had been melted, this could be recognized almost at a glance, even were it no larger than a small pin's head. But what is the result? The heat generated may have been sufficient to facilitate chemical change—for evidently, as an indirect result of the crushing, numerous minerals have been developed, which, however, generally are of very small size—but of any melting, in the proper sense of the word, of any conversion of the rock either into a volcanic glass or into a crystalline mass which may be produced under certain circumstances from the material of such a glass, not the slightest trace can be found. So that this hypothesis, attractive as it may be at first sight, appears to be destitute of any real foundation.

Difficult, then, as it may be to understand the precise agency by which masses of rock can be forced up to the neighborhood of the surface from depths of twenty to thirty miles, we fail to find any explanation of the high temperature, which is evidently a primary condition of volcanic action, more satisfactory than the proper internal heat of the earth. This, on the whole, is more accordant than any other with the present distribution of volcanoes; it is most in harmony with the phenomena, not only of volcanoes still

active, but also of igneous rocks in general. The chief volcanic regions of the globe, as already observed, either traverse or fringe the greater ocean basins. As will be seen later on, when the evolution of land masses is discussed, the principal regions for the deposit of sediment, and ultimately for processes of upheaval, folding, and mountain making, are those parts of the ocean basin which border the continents. Here, it must be remembered, the water is comparatively shallow; the surface of these masses of sediment, while still submerged, is often some two miles vertically above the general level of the old floor over a large part of the ocean. If, then, the crust of the earth is contracting from general loss of heat, this irregularity in the form of its outer surface, this departure from a true spherical outline, must tend to a further distortion of form. The inner, deeper, and comparatively level part of the trough may move with fair uniformity as a whole, but in so doing it will act like an arch on its abutments, and produce thrusts in an upward and outward direction, the effects of which will be most marked near its margin, and will be exhibited by uplifts and folds in that region. It is therefore possible that, as a consequence of these movements, masses of rock which were still in a plastic condition might be gradually extruded from beneath the subsiding margin of the deeper ocean floor toward the rising zone, and might ultimately be squeezed into cracks and cavities among the folding rocks. Sometimes these intruded masses may never reach the surface; at others, especially if brought into contact with water, they may break forth, more or less explosively, as volcanoes.

The mode in which igneous rocks occur accords generally with this idea of their origin. They appear sometimes to have made their way to the surface along innumerable fissures, as if a large area of rock had been strained until it yielded, and formed a series of parallel gaping cracks, through which the molten matter flowed; as may be seen in the cliffs of the promontory of Strathaird, in Skye (Fig. 62). Sometimes they have forced their way underground between two masses of uniformly stratified rock, occasionally with singular regularity, like a paper knife thrust between the pages of a book, as if the upper bed had been too solid to allow further progress in that direction, and yet the pressure from below on the plastic mass had enabled it to rend the layers apart, and to lift up the overlying one. In a fashion somewhat similar the melted material has occasionally poured out laterally for a more limited space around the upward channels of discharge, lifting the resisting

masses of sedimentary rock in the form of a flattened dome, sometimes even piercing into them for a little way by veins and similar offshoots, but assuming in the main a form rudely resembling a mushroom.* That masses such as these stand in the closest possible relation to the products of active volcanoes is demonstrated by comparison of the one with the other; the lava streams and dykes of the latter very closely resemble, if they are not identical with, the "sills" and dykes of the former. Among such rocks, if a series of examples be examined which are identical in chemical composition, it is possible to trace every stage of change, from the comparatively glassy material which has obviously solidified at or near the surface of an extinct volcano to the coarsely crystalline rock which had been cooled deep in the earth, and represents the once hidden sources from which formerly the lava streams were supplied. The adjacent rocks indicate by their condition that the temperature of the intrusive mass was once extremely high. A series of mineral changes have been produced which exhibit every stage, from simple induration or "baking," in the vicinity of small masses, which appear to have rapidly cooled, to the more or less complete obliteration of original structures and the rearrangement of constituents to form new combinations in the case of the larger and deeper seated intruders.

The probability that igneous rocks are not produced by the local melting down of sediments increases when their mineral composition and distribution, both in time and space, are more closely studied. If they were thus connected, a fairly close correspondence in chemical composition should exist between the igneous and the sedimentary rocks. Such a correspondence is exceptional. Instances, no doubt, of felspathic sandstones or of sandy shales can be selected which, on analysis, agree chemically with granite, for the simple reason that the breaking up of the latter has produced the former; but it is very difficult indeed to find among the sediments parallels with that very large group of igneous rocks of which basalt may be taken as a type, while the limestones, which are common in the former, and the olivine rocks, which are not very rare among the latter, remain in each case unmatched.† Inferences as to a common origin of two classes of rock cannot be

* These masses are technically called laccolites.

† Although peridotites (or rocks composed mainly of the mineral olivine, with little or no felspar) are rare, still serpentines (which have been proved to be merely altered peridotites) are not very uncommon.

made by selecting exceptional instances from either side; they must be founded on a comparison of the ordinary and dominant types in both. When this is done, the sedimentary rocks will be found to be generally either poorer in alkalies or richer in lime than the igneous rocks, which in other respects approach them most nearly in chemical composition, while they fail to afford any examples, like the latter group, of rocks rich in ferro-magnesian silicates. Igneous rocks, moreover, appear to be unaffected either by geographical position or by geological age.* A basalt from Europe may be indistinguishable from one found in Australia. A basalt which was ejected during the ages when the coal beds of Britain were being formed may be practically identical with one collected from a lava stream of recent date. All these considerations lead to the conclusion that, as a general rule, the igneous rocks are not portions of sedimentary rocks locally melted down, but represent the outer part of the magma of which the globe is composed.

* For many years the propriety of classifying igneous rocks by their geological age was stoutly maintained by many geologists, especially in Germany. In England it found little or no support, and quite lately the only argument in its favor which had any real value has been most seriously impaired. This classification was mainly founded on distinctions which were chiefly due to secondary changes; they were signs of difference in *age*, but not of difference in *kind*—that is to say, they were hardly more valuable for purposes of classification than the presence or the absence of gray hairs on men.

CHAPTER III.

EARTHQUAKES AND THEIR EFFECTS.

An earthquake is caused by the transit of a wave-like movement through the crust of the globe. It is a shudder of the cuticle, resulting from some sudden internal change or catastrophe. The tremor may be so slight as to be detected only by the most delicate instruments constructed expressly to record the faintest telluric disturbance, or it may shatter the strongest buildings, convert a city into a heap of ruins, and rend the solid ground. The feebler shocks may be compared to the vibrations produced in a slightly built house by the passage of a heavy train close at hand, either above ground or through a tunnel below (Londoners will appreciate the comparison), or to the concussion transmitted, often from considerable distances, by the explosion of a large quantity of powder. The greater shocks are the most terrible phenomena in nature. Familiarity with them does not breed contempt, but increases the dread which they cause, for when the solid earth rocks nothing seems secure; the nervous system is shaken by the strangeness of the experience, and above all by the seeming treacherousness of the visitations, for the hurricane gives some warning, brief though it may be, of its approach, the volcano some indication that danger is impending, but with the earthquake at one minute all is peaceful, at the next the land is quivering like an aspen, prosperity has given place to ruin, and joy to sorrow.

Sometimes only a single shock is observed. This may be almost instantaneous in its passage, or it may consist of a group of continuous vibrations of variable intensity, which may occupy some minutes—wave following wave along the crust, which is occasionally seen actually to rise and fall like the surface of a liquid. Sometimes also the shocks may be repeated at uncertain intervals for days, or even weeks, together. Be this as it may, whether the shocks be slight or strong, few or many, the concussion, as will be seen, appears to originate in some definite locality, and at some distance beneath the earth's surface. There is, then, as might be anticipated, a marked difference in the phenomena, according as

the center from which a disturbance has been propagated is situated under the dry land or in the earth's crust beneath the ocean. Suppose—at present only for the purpose of illustration—the earthquake to be caused by a subterranean explosion. In both the cases a sound wave travels, and a shock is transmitted through the crust, but in the former one these continue their course until they reach the surface. In some instances the noise precedes, in others it succeeds, the tremor; in others the two are practically simultaneous. It is variously described as "a hollow booming sound," "like distant thunder," "the rolling of a heavy wagon," or "the bellowing of

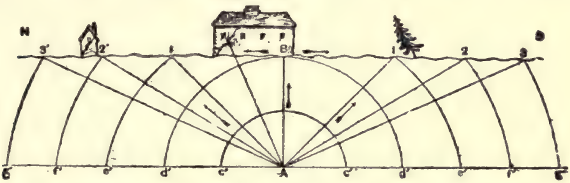


FIG. 108.—DIAGRAM ILLUSTRATING MALLET'S THEORY OF THE DIRECTION OF MOVEMENT FROM AN EARTHQUAKE FOCUS.

A, Earthquake focus, or center of impulse; B, Seismic verticle. The lines A 1, A 1', A 2, A 2', A 3, A 3', represent the direction of the movement from A. The position of circles shows the depths at which the shock would be felt at the same time—*i. e.* the particles would move on the lines c c', d d', and so on, as if these were sections of hollow shells placed one over the other. The wave would reach the surface first at B, and travel from it north and south, occurring simultaneously at the coseismic points 1 and 1', 2 and 2', 3 and 3'.

bulls." Assuming the earth's surface to be level on the region in question, the shock is first felt at a spot directly above that where the disturbance has originated. Here it acts in a vertical direction—buildings, columns, pavements, all things resting on the ground, are jerked or lifted quickly upward. So, if masonry is damaged, the cracks run horizontally, and though roofs may collapse, and colonnades may totter with the vibration, the tendency to overthrow them is but slight. It is also possible that an impulse may be set up in, and a sound wave communicated to, the air above the place where the shock emerges; these, however, are usually unimportant phenomena, and often pass unnoticed. So long as no change takes place in the materials of the crust the shock travels uniformly outward from the focus of the disturbance. Hence all the points which lie on the surface of a sphere described about this focus as a center will be simultaneously and correspondingly affected. It follows, therefore, as a glance at the annexed diagram will indicate, that the

shock appears to spread outward along the ground in a circular form from the point * where it has been first perceived, just as waves travel on the surface of a quiet pool when a stone is dropped from a height into the water; but as the circle widens, the direction is changed in which the impulse seems to act. The uplift produced by the shock becomes more and more oblique. Thus columns, chimneys, spires are more likely to be overthrown, and to fall, either forward or backward, in the direction of a radius of this circle. The cracks in a wall are no longer horizontal, but pass from course to course of masonry, and make an angle with the horizon, which becomes higher as the place is more remote from the original center of disturbance. If, then, a number of observations be obtained, sufficient for the elimination of accidental variations and for securing trustworthy averages, a very simple mathematical calculation suffices to determine, with considerable precision, the depth at which the shock originated. Again, if careful note has been taken of the time at which the shock has been felt at a series of stations lying at different distances from the seismic vertical, the rate at which the wave has traveled can be also ascertained.

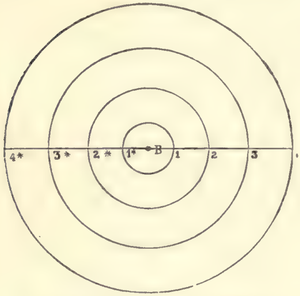


FIG. 109.—DIAGRAM OF SEISMIC CIRCLES.
B, Seismic vertical; 1 1*, 2 2*, 3 3*, 4 4*, Coseismic points on the circles.

If, however, the place where the shock originated is beneath the bottom of the sea, the phenomena of an earthquake become more complex. Here also the disturbance emerges vertically, and it communicates a shock to the overlying mass of water. This produces a great sea wave, exactly as an undulation may be started in the water filling a flat pan by giving a sharp tap at the bottom. The shock, however, also continues to travel through the earth's crust beneath the sea; but the disturbance becomes insufficient to produce any appreciable effect on the overlying water so long as this is deep; but when this is shallow, as the shore is approached, the shock gives rise to an undulation called the "forced sea wave." We can often observe, as we walk along the bank of a pool, that a

* Generally called "the seismic vertical."

fish, in darting from its lurking place, indicates its path by a rise in the water, which disappears as it enters the deeper parts. A similar effect, but in reverse order, is produced by the earthquake shock as it passes under the shallow water. An observer standing on the shore sees a wave larger than usual approaching, which rides, as it were, on the back of the shock, and breaks on the land just in its rear. Immediately afterward he feels the tremor, and perhaps hears a rumbling noise. After taking note of this, if he be a prudent person, and the coast a low one, he will betake himself as quickly as possible to some fairly high ground and watch the course of events. The shock does not always travel through the earth at the same pace, because this, as will presently be shown, depends upon the nature of the rock; but it almost invariably outstrips the wave which has been generated in the open ocean, the velocity of which is about 1138 feet a second. When the latter reaches the land, it is far more formidable than the wave which accompanied the shock. Rising higher as it comes into the shallower water, the huge mass breaks upon the coast, sometimes rushing far inland like a sudden deluge, bringing death and destruction in its reflux, and sweeping out to sea the corpses of men and cattle. When the shock originates as last described, a sound wave and a vibration may be communicated from the original focus of disturbance through the ocean to the air above it. This phenomenon, however, generally is unimportant, and frequently is not noticed.

In the British Isles earthquakes are by no means uncommon, though, happily, they have rarely done any serious damage, and only in very few cases caused loss of life. They are rather frequent in certain parts of Scotland, especially along the line of the Great Glen and about Comrie, in Perthshire. Records have been found of more than three hundred and fifty, and, doubtless, many more of a slighter character have escaped notice. Buildings were more or less damaged by fifty-nine of these, and in a few cases persons are said to have been killed. The earthquake of April 15 (?), 1185, seriously injured Lincoln Cathedral, and one in the following year did nearly as much mischief; that of December 21, 1248, damaged the cathedrals of Wells and St. David's. In 1246, 1275, 1382, 1580, "churches were thrown down," but the most severe on record for four centuries occurred on April 22, 1884.* The focus of the dis-

* It is described and discussed in an admirable and exhaustive report by Professor R. Meldola and Mr. W. White: "Report on the East Anglian Earthquake" ("Essex Field

turbance seems to have been situated nearly beneath the village of Abberton, in Essex, and the shock was felt from Brigg, in Lincolnshire, to Freshwater, in the Isle of Wight, and from Street, in Somersetshire, to Ostend, in Belgium, over an area altogether of full 50,000 square miles ; but the damage was limited to a comparatively small area in the Eastern Counties, and was more severe on the stiff clay—the London Clay of geologists—than on the drift and alluvial deposits. Walls were cracked, chimney stacks were shattered and occasionally fell, and in Colchester the upper part of a slightly built spire was thrown down. Altogether 1200 to 1500 buildings were damaged, though in many instances the injuries were slight, but no harm was done to life or limb. The shock, which occurred about 9.18 A. M., appears to have been composite in character, two oscillations having been distinctly noticed by some observers; t was accompanied by a rumbling noise, like distant thunder. It traveled at a rate estimated from 9000 to 10,000 feet a second. Data sufficient to fix the position of the focus of the disturbance could not be obtained, but it was very probably due to a movement in the hard and ancient rock mass which is known to underlie, at a depth of some 1000 or 1200 feet, the comparatively soft chalk and later rocks of East Anglia.

Far more terrible than any such disaster ever experienced in the British Isles was the earthquake of Charleston in 1886. South Carolina appears to be rather subject to this calamity, for a description of severe earthquakes which occurred in 1812, and in some cases altered the level of the land, will be found in Sir C. Lyell's "Principles of Geology."* In the early summer of 1886 several slight tremors occurred, which, however, did not excite much attention. More distinct shocks were felt on August 27 and 28, and the great shock occurred in the evening of August 31.† The atmosphere that afternoon had been unusually sultry and quiet, the breeze from the ocean, which generally accompanied the rising tide, was almost entirely absent, and the setting sun caused little glow in the sky. "As the hour of 9.50 was reached there was suddenly

Club, Special Memoirs," vol. i.), from which all the particulars concerning English earthquakes have been taken.

* Ch. xxviii.

† A history of this earthquake, with illustrations of the effects produced and a very elaborate discussion of the observations, by Captain C. E. Dutton, is printed in the "Ninth Annual Report of the United States Geological Survey," from which the particulars given above are taken.

heard a rushing, roaring sound, compared by some to a train of cars at no great distance, by others to a clatter produced by two or more omnibuses moving at a rapid rate over a paved street, by others, again, to an escape of steam from a boiler. It was followed immediately by a thumping and beating of the earth underneath the houses, which rocked and swayed to and fro. Furniture was violently moved and dashed to the floor; pictures were swung from the walls, and in some cases turned with their backs to the front, and every movable thing was thrown into extraordinary convulsions. The greatest intensity of the shock is considered to have been during the first half, and it was probably then, during the period of the greatest sway, that so many chimneys were broken off at the junction with the roof.* . . The duration of this severe shock is thought to have been from thirty-five to forty seconds. The impression produced upon many was that it could be subdivided into three distinct movements, while others were of the opinion that it was one continuous movement, or succession of waves, with the period of greatest intensity, as already stated, during the first half of its duration." † Twenty-seven persons were killed outright, and more than that number died soon after of their hurts or from exposure; many others were less seriously injured. Among the buildings the havoc, though much less disastrous than has been recorded in some other earthquakes in either hemisphere, was very great. "There was not a building in the city which had wholly escaped serious injury. The extent of the damage varied greatly, ranging from total demolition down to the loss of chimney tops and the dislodgment of more or less plastering. The number of buildings which were completely demolished and leveled to the ground was not great; but there were several hundred which lost a large portion of their walls. There were very many also which remained standing, but so badly shattered that public safety required that they should be pulled down altogether. There was not, so far as at present known, a brick or stone building which was not more or less cracked, and in most of them the cracks were a permanent disfigurement and a source of danger and inconvenience." In some places the railway track was curiously distorted. "It was often displaced laterally, and sometimes alternately depressed and elevated.

* The number was counted afterward, and found to be almost 14,000.

† "Report," p. 231, from an account contributed by Dr. Manigault. An account is also printed from the pen of one of the staff of the Charleston *News and Courier*, which supplies, perhaps with a little picturesque coloring, many interesting minor details.

Occasionally severe lateral flexures of double curvature and of great amount were exhibited. Many hundred yards of track had been shoved bodily to the south eastward."

At Charleston the ground was fissured in places to a depth of

FIG. 110.—STREET HOUSES IN CHARLESTON DAMAGED IN THE SOUTH CAROLINA EARTHQUAKE OF 1886.

many feet, and numerous "craterlets" were formed, from which sand was ejected in considerable quantities. Both these phenomena are not unusual in earthquakes. During one which occurred in New Zealand in 1825 a cleft opened which could be traced for about ninety miles, the ground in one part being permanently upraised to a height of as much as nine feet. Similar fissures and craterlets were formed in South Carolina during the earthquakes of 1811–12,

as well as in those which devastated Calabria in 1783. The craterlets are due, no doubt, to the squirting out of water from saturated sandy layers not far below the surface, as they are squeezed between two less pervious beds by the passage of the wave. The ejected material in the Charleston earthquake was ordinary sand, such as might have been obtained in many districts which have been quite undisturbed by any concussions of the earth.

Captain Dutton has made a careful study of the observations collected by himself and others, and has come to the conclusion that the Charleston wave traveled with unusual speed, for its mean velocity was about 17,000 feet a second.* The focus of the disturbance was also ascertained. Apparently it was a double one, the two centers being about thirteen miles apart, and the line joining them running nearly the same distance to the west of Charleston. The approximate depth of the principal focus is given as twelve miles, with a possible error of less than two miles; that of the minor one as roughly eight miles.

In Japan, which might almost be called a land of earthquakes, for in the year 1888 no less than 630 shocks were observed, similar results, on a yet greater scale, were produced by the terrible shock of October 28, 1891. Professor Milne, who for some years past has carefully studied the earthquakes of Japan, has recently described the effects and published photographs of certain of the more remarkable.† On this occasion the tremors lasted for some minutes. At Tokio the earth rocked, the water in a tank was splashed over the edge, the trees were swinging about, the telegraph wires were clattering together, and the effect of the motion was to make him feel giddy and slightly seasick. Chimneys fell, houses, temples, and factories were shattered, bridges were broken, roads and railways distorted by vertical and lateral twists, several embankments destroyed, the ground was fissured in all directions, and mountain sides slipped down and blocked the valleys. The disturbance, according to Dr. B. Koto, is connected with the formation of a great fault which can be traced on the surface of the earth for a distance of between forty and fifty miles. "In the Neo valley, where it runs nearly north and south, it looks like one side of a railway embankment about twenty or thirty feet in height. The fields at

*The mean of the calculations amounted to 17,008 feet a second, with 262 feet as the probable limit of error.

†Milne and Burton, "The Great Earthquake in Japan." See also "British Association Report," 1892, p. 93.

the bottom of this ridge were formerly level with the fields now at the top of it."* Along this line horizontal displacements also have been noticed. Here plots of land once adjacent have been parted; there the ground has been actually compressed, and the breadth of a tract been diminished by half a dozen yards. Since the great shock

FIG. 111.—FISSURE PRODUCED BY AN EARTHQUAKE, BELLA, CALABRIA. (*After Mallet.*)

about 3000 minor shakings have been noticed, with the result that "in an area of 4176 square miles, which embraces one of the most fertile plains of Japan, and where there is a population of perhaps 1000 to the square mile, all the buildings which had not been reduced to a heap of rubbish had been badly shattered. To rebuild the railway, reconstruct bridges, roads, and embankments, and to

* "British Association Report," 1892, p. 117.

relieve immediate distress, about one and three-quarters million pounds sterling have been poured into the district, the greater portion of which came from the Imperial Treasury. This sum, however, only measures a fraction of the total destruction. One hundred thousand homes have yet to be rebuilt; irrigation works have to be repaired; a value has to be given to land which has been buried by landslides, or lost by what appears to be a permanent compression of valleys; there has been a six months' interruption of traffic and industries, and nearly 10,000 people have lost their lives."

The Nagoya-Gifu district, where the earthquake was very severe, is a flat expanse of rich alluvium, fringed on its east and west sides by low hills of comparatively incoherent and, geologically, rather recent materials. These lie at the foot of a mountain range which rises to a height of from 2000 to 4000 feet, and consists of slates, limestones, and crystalline rocks, without any signs of volcanic action.

Among modern earthquakes one which occurred in Ischia on March 4, 1881, presented some peculiarities. The shock was severe, for many houses were destroyed, and 127 persons were either killed on the spot or died of their injuries, but the area over which it produced any sensible effect was very limited. At Naples it was not felt, and even at Capo di Miseno, only some eight miles away, it was barely noticed. The focus of disturbance was evidently beneath a part of the island; the roofs and floors of houses in Casamenella collapsed, but the walls were not generally thrown down; around this area the angle of emergence of the shock rapidly diminished. Obviously, then, the disturbance must have originated near to the surface. It was probably connected with Monte Epomeo, the culminating point of the island, which is a ruined crater, extinct itself, though eruptions from parasitic cones have occurred in historic times. A second very disastrous earthquake occurred on July 28, 1883, by which a somewhat larger area was affected.* Ischia obviously, notwithstanding other attractions, is not a desirable place of residence, for a day may come when Monte Epomeo may repeat the kind of performance by which Vesuvius some eighteen centuries since celebrated its return to the list of active volcanoes.

Among the less recent earthquakes that of Caracas is noted for the frightful destruction of life and property. On March 26, 1812, "several violent shocks of an earthquake were felt. The surface

* "British Association Report," 1883, pp. 409, 501.

undulated like a boiling liquid, and terrrific sounds were heard underground. The whole city, with its splendid churches, was in an instant a heap of ruins, under which 10,000 of the inhabitants were buried."* The earthquake of Lisbon in 1755 produced consequences yet more disastrous. "The inhabitants had no warning of the coming danger, when a sound like thunder was heard underground, and immediately afterward a violent shock threw down the greater part of their city." Numbers of persons were buried beneath the ruins; many of the survivors rushed toward the quays, but the sea first retired and then rolled in, rising 50 feet or so above its ordinary level. On one quay, which had been recently built at a very heavy expense, "a great concourse of people had collected there for safety, as a spot where they might be beyond the reach of falling ruins; but suddenly the quay sank down with all the people on it, and not one of the dead bodies ever floated to the surface. A great number of boats and small vessels anchored near it, all full of people, were swallowed up as in a whirlpool. No fragments of these wrecks ever rose again to the surface." The account of this catastrophe, as Sir C. Lyell observes,† is clearly exaggerated, and the disappearance of the pier seems almost unaccountable, for the depth of that part of the Tagus, even at high tide, does not exceed 30 feet. He suggests that possibly a deep narrow chasm may have opened in the bed of the estuary and closed again after swallowing up some vessels and adjoining buildings. If so, this must have been the result of a second shock, for some minutes had elapsed evidently since the first one, as the people had collected on the quay. Possibly the following may be the true explanation: The strata near the river appear to consist of rather loose and incoherent materials. By the first shock these may have been disturbed, and the foundations of the pier so seriously shaken that its stability was destroyed. Hence, when the great sea wave rushed upon it, the whole mass of masonry, with the clayey substructure on which it rested, may have slipped bodily forward into the water, and the shattered fragments of the pier, with the submerged vessels and the drowned bodies, may have been entombed in the fluid mud which would be stirred up by the catastrophe. The landslip at Zug in 1887, visited by myself, illustrates the manner in which I conceive the disaster to have occurred. A broad strip of land bordering the

* Lyell, "Principles of Geology," ch. xxviii.

† *Ibid.*, ch. xxx.

lake had slipped suddenly forward into the water. The houses upon it were reduced to mounds of brickwork, here and there rising above the surface. The *débris* of the land, with part of the bed of the lake, appeared to have glided outward, so that the disturbance extended for above a thousand yards from the shore.*

Not the least remarkable feature in the earthquake of Lisbon was the unusually large area over which the shock was felt. According to Humboldt this was four times greater than the extent of Europe. The earlier statements, however, appear to be exaggerated, for all disturbances which occurred about the same date were at once set down to the convulsion which shattered Lisbon. Thus it may be doubted whether this earthquake shook New York or disturbed the waters of Ontario, or, indeed, was felt anywhere in North America, though the sea wave which it originated does appear to have crossed the Atlantic and dashed upon the coasts of Barbadoes and Martinique, where the water rose a dozen feet or more above its usual tidal level. But the shock was certainly felt over an area at least six times the size of France, and is generally believed to have been sensible in Scotland, where the water of Loch Lomond rose and fell for rather more than two feet. In England it was unnoticed, doubtless for this reason: the shock probably originated in hard and ancient rocks, through which its main influence would be propagated. These, in the eastern part of England, lie at a considerable depth—generally full a thousand feet below the surface—and are covered up with less coherent materials, but they emerge to the air in Scotland. The shock, of course, as it traveled would be communicated to the overlying rocks, but among them its effects would be speedily dissipated; just as slight vibrations in a bedstead would not affect anyone upon it if he lay on the top of a thick feather bed

No district, however, in Europe has a worse repute for earthquakes than Calabria, and in none have they been more carefully studied. From 1783 to 1786 the shocks were frequently repeated; the land suffered from an epidemic of tremors. In the former year 949 shocks were observed, and 151 in the year following. The district was visited by a deputation from the Royal Academy of Naples, and by other men of science, including Sir W. Hamilton, who made careful observations, which were afterward published. Again, in 1857 Calabria passed through another phase of earth-

* *Nature*, vol. xxxvi. p. 389; also vol. xxxviii. p. 268.

quakes; these were studied by Mr. Mallet, and described in his well-known work.* The region affected consists partly of thick clayey strata, associated with occasional beds of sand and limestone deposits, all comparatively incoherent, partly of harder and more schistose rocks, and of granite; these rise from beneath the others

FIG. 112.—CATHEDRAL OF TITO, CALABRIA, AFTER THE EARTHQUAKE OF 1857. (*After Mallet.*)

to form the mountainous district, a prolongation of the Apennines. In the earlier earthquakes the worst shocks appear to have occurred on February 5 and on March 28, 1783. The region, however, which was very seriously affected was not large, for its area was only about 500 square miles. "If the city of Oppido, in Calabria Ultra, be taken as a center, and round that center a circle be described with a radius of twenty-two miles, this space will comprehend the surface of the country which suffered the greatest alteration, and where all the towns and villages were destroyed." † At times the surface of the land seemed to heave "like the billows of a swelling sea . . . trees, supported by their trunks, sometimes bent during

* "The Neapolitan Earthquake of 1857."
† Lyell, "Principles of Geology," ch. xxix.

the shocks to the earth, and touched it with their tops" ; water and sand were discharged from craterlets, as above described, fissures opened in the ground,* changes of level occurred, and landslips

FIG. 113.—STREET VIEW IN LA POLLA AFTER THE EARTHQUAKE OF 1857.

were numerous and formidable. The shocks were exceptionally destructive to property in consequence of a peculiarity in the geological structure of the country. In the lower parts of the valleys in the hill districts the incoherent clays mentioned above rest upon the older and harder rocks, having been deposited upon them, after the broad outlines of the physical structure of the country had been produced, as muds might be laid down at the present day in a sea loch or estuary on the Scottish coast. After

* These are said to have yawned wide enough to engulf houses, on which they sometimes closed. It is possible, however, that in some cases the phenomena described may be not so much the direct result of a fissuring of the ground under the strain caused by the passage of an earthquake wave as the consequence of a slipping of the mass, when its tension would be much greater, and large cracks would open and close as it moved along.

the land had been elevated above the sea, streamlets cut deep gashes into these clays, and rivers washed away large portions, leaving the remainder in insulated masses, projecting outward from the mountain flanks and sloping steeply down to the present beds of the valleys. These flat-topped bastions, from their obvious natural advantages, had become the favorite site for villages; but in them the buildings suffered much more severely than in those on the harder rock. The shock travels more slowly through incoherent than through solid materials, and so produces usually more serious consequences. The change also in the character of the rock is apt to cause secondary or reflected shocks near the junction, and in this case the peculiar configuration of the surface facilitated actual landslips and settlements in the less coherent materials. A village thus situated may crumble into ruins as the shudder passes through the ground. In some places even huge masses of cliff or portions of a hillside fell or slipped bodily away. On the coast the terrible sea wave more than once swept in and inundated the lowlands. Near Scylla, of classic fame, its "dogs of death" swooped down, and might be said to have joined hands with Charybdis. On the night of February 5 the people, at the advice of their prince, had taken refuge in their boats. Suddenly, after a terrible convulsion, a huge wave rolled in upon the land, and then swept back to sea. Every boat was swamped or wrecked; the prince, with 1430 of his people, perished.

The observers of some of the earlier earthquakes believed that the ground was occasionally affected by an eddying movement. This idea, which in itself does not appear to be very intelligible, was effectually disposed of by Mr. Mallet, who showed that the lateral displacement which the stones suffered in certain structures was simply the effect of an ordinary shock, and could be explained by well-known mechanical laws. He obtained a large number of observations, from which he calculated that the depth of the focus of disturbance in 1857 did not exceed seven or eight miles, and perhaps was not more than five.

Two earthquakes of great severity, which occurred during the present century, within three years one of another, are remarkable for producing an unusual and extensive alteration in the level of the ground. The one, which happened on June 16, 1819, chiefly affected the province of Cutch, especially in the neighborhood of the eastern channel of the Indus; but its vibrations were felt inland in various directions to a distance of 1000 miles from the chief seat

of the disturbance. Towns were ruined and rocks shaken down from the hills, but the most remarkable changes were in the Runn of Cutch, an enormous salt marsh larger than Yorkshire, which runs back for a long distance inland from the head of the Gulf of Cutch. It is flooded by the sea at certain states of the tide and wind, and is traversed on its western side by a channel of the Indus. This, prior to the earthquake, could be forded at a place called Luckput, for the depth at low water was only about a foot; even at high water it did not exceed a couple of yards. After the shock the depth was increased to 18 feet at low water. "By this and other remarkable changes of level a part of the inland navigation of that country, which had been closed for centuries, became again practicable. Not less marked results were produced at Sindree, a village above Luckput. Here a fort stood near the water side and a few feet above it.* From one angle a massive circular tower, like the keep of a European castle, rose to some height above the general level of the walls and smaller towers. After the shock the sea rushed up the eastern mouth of the Indus and permanently flooded an area of land about 2000 square miles in extent. The village of Sindree disappeared, the fort was almost submerged, only the top courses of its walls and the upper part of the "keep" projecting from the wide expanse of water. This, however, was not the sole change; the subsidence was to some extent compensated by elevation. The inhabitants of Sindree saved themselves by taking refuge on the top of the "keep," and from it they saw, "at the distance of five and a half miles from their village, a long elevated mound, where previously there had been a low and perfectly level plain. To this uplifted tract they gave the name of Ullah Bund, or the 'Mound of God,' to distinguish it from several artificial dams thrown across the eastern arm of the Indus." Its extent from east to west—that is, parallel to the line of the main subsidence—was more than fifty miles, its breadth at the widest part was about sixteen miles, and its greatest elevation above the original level was ten feet. This height was maintained over a large portion of the mound. During the next few years after the earthquake the Indus made considerable variations in its course—among other things cutting through the Ullah Bund—but the change in level appears to have been per-

* In the "Principles of Geology," ch. xxviii., two sketches are compared, which show the place before and after the earthquake. Reference to this earthquake has been already made on p. 204.

manent, and a further subsidence in the Runn, according to Sir C. Lyell, occurred after an earthquake in June, 1845.

The coast of Chili, on November 19, 1822, was shaken by a violent earthquake. It affected a very large area, but was especially destructive at Valparaiso, St. Jago, and Quintero. Several of the phenomena already mentioned were observed, but the most remarkable was the permanent uplifting of a considerable tract of the South American coast to a height of from three to four feet. Rocks with oysters and other mollusks, or with beds of seaweed still attached, were raised above the sea, and the change appears to have been permanent. That it was not the first movement in an upward direction is indicated by "several older elevated lines of beach, one above the other, consisting of shingle mixed with shells, extending in a parallel direction to the shore, to the height of 50 feet above the sea." * According to Mr. Darwin and Captain Fitzroy,† the same region was further elevated by an earthquake which occurred on February 20, 1835. "The southern end of the island of St. Mary was uplifted eight feet, the central part nine, and the northern end ten feet, and the whole island more than the surrounding districts. Great beds of mussels, patellæ, and chitons, still adhering to the rocks, were upraised above high water mark; and some acres of a rocky flat, which was formerly always covered by the sea, were left standing dry, and exhaled an offensive smell from the many attached and putrefying shells." In this case the elevation appears not to have been altogether permanent, for the land in the course of some weeks subsided for four or five feet. But Mr. Darwin's observations of this coast clearly indicate that a very long strip of it (doubtless associated with a considerable part of the parallel mountain chain of the Andes) has been upraised by successive movements, within comparatively recent times, to a height which is sometimes not less than 400 feet.

Observations of the rate at which an earthquake shock travels give very different results. Some years since a series of experiments was made by the late Mr. Mallet in order to ascertain the probable velocities of propagation on the hypothesis that the time of transit stands in a certain relation to the elasticity of the rock. The results thus obtained gave figures ranging from 3640 feet a second in a limestone from the Lias, to 12,757 feet in a slate from Charn-

* "Principles of Geology," ch. xxviii.

† "Geological Observations," part ii. ch. ix.; "Voyages of Adventure in the *Beagle*," vol. ii. p. 415.

wood. In the harder limestones the velocity was from nearly six to about seven thousand feet a second. These results, however, assumed the rock to be solid, and not traversed by cracks, joints, or divisional surfaces of any kind, so that in each case they would be in excess of the truth. The results deduced from actual observation are yet more diverse. A shock produced by an explosion of gunpowder at Holyhead was observed by Mr. Mallet to travel at the rate of almost 825 feet a second in wet sand, and of about 1665 feet in solid granite; and disturbances produced by exploding dynamite, observed by Professor J. Milne, in Japan, went even slower—viz., from 200 to 630 feet a second. The rate of an earthquake wave at Travancore was as low as 656 feet a second; that in the Calabrian earthquake of 1857 only 789; that of Herzogenrath, in 1877, had a velocity of 1555 feet, and that in the Pennine Alps, in 1855, traveled as far as Turin at the average rate of 1398 feet a second, and to Strasburg at that of 2861 feet, while one in Central Europe, in 1872, gave a rate of 2433. Earthquake shocks in Japan have traveled on different occasions at about 5100, 8000, and 9800 feet a second. But the velocity of the Charleston earthquake, as already stated, amounted to 17,008 feet a second—a pace unaccountably rapid; but the result is supported by a determination made by General Abbott at the destruction of Flood Rock, in the United States, where the shock traveled at the rate of 20,526 feet a second. Professor J. Milne has come to the conclusion that the velocity of transit decreases as a disturbance radiates, and varies with the initial intensity of the disturbance.*

Of late years the more careful study and record of earthquakes have led to some interesting results. It is now probable that they occur more frequently at certain seasons of the year and hours of the day. Of 1230 earthquakes observed in Switzerland,† only 435, or just over 35 per cent., happened in the six months' period from April to September inclusive; the smallest number of shocks (40) was in July; the largest (165) in December, and from the one to the other there was a fairly regular increase. May, June, July, and August were comparatively quiet months, the total number of shocks registered during these being 199; December, January, February, and March were correspondingly disturbed, 599 shocks occurring in this period. Between August and September the

* "British Association Report," 1892, p. 127.

† Réclus "The Earth," ch. lxxviii.

FIG. 114.—EARTHQUAKE MAP OF THE WORLD.

increase is marked, and the decrease is not less so between April and May.*

Another set of observations leads to the conclusion that earthquakes are lovers of darkness. Of 502 recorded in Switzerland, the times of which are known, 320, or 64 per cent., occurred between 6 P. M. and 6 A. M.† Some have thought that a connection can be traced between the frequency of earthquakes and of sun spots; but this, until more data have been ascertained, cannot be regarded as established. Professor G. Darwin has pointed out that the pressure upon large areas of the earth's surface must be considerably modified by changes in the level of the ocean due to the tide. When there is a difference of five yards between high and low tide, this means the addition or subtraction of a pressure of more than seven pounds to the square inch, or about half an atmosphere, and it must be remembered that the fluctuations in the pressure of the atmosphere itself, when operating on large areas, may not be wholly negligible, and may play the part of the proverbial last ounce.

But although various circumstances more or less external may possibly have an indirect influence upon the occurrence of earthquakes, the primary cause undoubtedly must be sought within the crust of the earth itself. The depth of the center of disturbance appears not to exceed about thirty miles, and is very commonly from about five to ten miles, and a study of a chart of the regions most affected by earthquakes leads to the conclusion that they are frequent where volcanoes either are still active or but recently, geologically speaking, have become extinct (Fig. 114). They are also frequent in regions which are distinctly mountainous, such as the Alps, the Apennines, the Andes, the Rocky Mountains; old hill districts also, such as the Scotch Highlands and part of the Spanish peninsula, are commonly disturbed. Not seldom the two apparent causes are united in the same region, as in New Zealand and in Japan, where earthquakes are chronic; though, according to Professor J. Milne, the majority of those which he has observed in that country do not come from the volcanoes, nor do they seem to have any direct connection with them. We can readily understand that in a volcanic region the earth's crust may be sometimes shaken by

* Professor J. Milne's observations of 101 earthquakes felt in 1888, at Tokio, show an irregular distribution, and hardly any difference.—"British Association Reports," 1892, p. 98.

† This also is not borne out by Professor Milne's observations, the difference being small, but the after-midnight hours are slightly the less disturbed.—*Ibid.*, p. 99.

the subterranean explosion of gases, or may be rent asunder by the pressure of a mass of lava as it forces its way underground, or may tremble from the sudden subsidence of strata which have been left unsupported by the condensation of vapor. The explosion of a powder barge at Erith, on October 1, 1864, made the ground quiver slightly even at Cambridge; and when 10,000 pounds weight of gunpowder blew up in the mills at Mainz, the tremor was felt more than a hundred miles away. In mountain regions also, and wherever rocks are being either bent into folds or broken by faults, large masses may yield suddenly to strains, and so produce sometimes a tremor which merely suffices to agitate a seismometer, sometimes a shock which shatters a city. As important landslips on the surface often cause the ground to quiver for miles round, so the jar produced by the sudden cracking and slipping of a mass of rock beneath it may originate vibrations which will extend for long distances.

Professor Milne remarks that "earthquakes generally occur in mountainous countries where the mountains are geologically young, or in countries where there is evidence of slow secular movements like elevation. These latter movements are usually well marked in volcanic countries, and it is not unlikely that the majority of earthquakes, even in volcanic countries, are the result of the sudden yielding of rocky masses which have been bent till they have reached a limit of elasticity. The after-shocks are suggestive of the settling of disjointed strata."*

It must not, however, be forgotten that even very ancient mountain regions, such as the Scotch Highlands or the Welsh hills, are by no means, even yet, at rest, and that volcanic districts where no evidence of any marked flexure of the crust is forthcoming are not seldom affected by rather long-continued, if not very severe, disturbances. Serious earthquakes also, like that of Charleston, sometimes occur in level districts, in which are no signs of volcanic action, and where a mountain range, if it ever existed, must have been long since planed down by denudation, and must be now buried deep beneath the surface. Still it is probably true that the more serious shocks are due, as a rule, to processes of mountain making. It is impossible that such folding, crushing, and overthrust faulting, as are indicated no less plainly in the Highlands of Scotland than in the mountain ranges of the Alps, could have occurred without frequent starts and slips, and consequent earth shudders. We are

*"British Association Reports," 1892, p. 128.

prone to assume, often almost unconsciously, that these movements are at an end, and that no changes are taking place in those parts of the earth where nature seems in placid mood and we have the good fortune to live, but this assumption is not supported by any real evidence. We have seen that in many regions the level of the land has been very materially altered within the last few centuries, sometimes within the last few decades. Hence we are not entitled to say more than that in these other districts no changes have occurred which can be readily perceived. There may be a slow rise of the surface here, a slow fall there, in either the Highlands or the Alps, which only a series of very careful observations could detect, and it would be well if even in the British Isles a line of levels were taken from the seacoast across some suitable district where earthquakes were frequent and good bench marks could be made, and were repeated, say, every fifty years, in order to ascertain whether the surface of the ground is perfectly at rest.

CHAPTER IV.

INTERNAL CHANGES IN THE EARTH'S CRUST.

THE uplifting and the downsinking of masses of land, the volcano and the earthquake, are but the more obvious signs of processes of change which are ever at work in the crust of the earth. Into these, interesting though some of them may be, it is impossible to enter fully in the present volume, for the subject is often extremely difficult, and a discussion of its details cannot be made intelligible until a considerable amount of rather minutely technical knowledge has been acquired. We must therefore be contented with certain general statements as to the nature of these changes and indications of the more conspicuous results to which they have directly or indirectly contributed.

One group of changes is mainly mechanical, another is mainly chemical. Though a hard and fast line cannot be drawn between the two, some advantage on the side of simplicity may be found in adopting this rough classification. A passing reference has been already made to some of the most striking phenomena in the former group. By means of the pressures set up when masses of rock are sharply folded, as happens in the formation of a mountain chain, the structure called cleavage is produced, the rock being traversed by divisonal planes, often very near together, which are quite independent of and generally different from those due to the original lamination of the bed. The latter frequently so completely disappear as to be distinguished only by differences in grain or in tint, indicating bands running athwart the edge or across the face of the slab. That the slaty structure is a result of pressure cannot be doubted; fossils are distorted, and the particles of the rock are elongated parallel with the planes of cleavage; the latter effect, even if it be not visible to the naked eye, is always conspicuous on microscopic examination. In not a few cases also the intimate relation between the axes of the folds which have been formed in a banded rock and the direction of the cleavage planes proves that both must be the results of the same set of forces.

By movements also of the crust large masses of rock, as already mentioned, have been displaced relatively, and faults have been formed. Portions of rock which were once in contact are so no longer. The displacement may be mainly in a vertical direction, or also largely a lateral one; it may be measured only by inches, or by thousands of feet. In the last case it is most probable—we might venture to say almost certainly—the result of a series of movements, continued, doubtless, with intervals of repose, through long periods. A fault may be often traced through rocks differing widely in geological age, and the displacement in the newer series will be much smaller than that in the older one. Hence it is evident that, during the interval between the formation of the two rock masses, the latter was disturbed and displaced. Its surface was subsequently planed down by denudation, and on this comparatively level floor a new set of beds was deposited. Then the whole mass was subjected to a strain acting in the old direction; the original fault had produced a line of weakness in the crust, along which it again yielded, so that both sets of beds were affected, but the newer bear record of one displacement only, while the older have been twice moved. Faults sometimes produce marked effects on the scenery of a region. As they may bring, when the displacement is considerable, masses of rock into contact which differ very much in hardness and durability, they may determine the direction of valleys and the trend of escarpments; but in many instances they so little modify the surface as to be only detected on a close and careful examination. In such cases the geologist infers their existence either by finding masses of rock outcropping in apparent sequence, which from his previous studies he knows to be really separated by considerable intervals—that is to say, by the unexpected disappearance, as it seems, of pages or chapters from the geological record, or by the peculiar and abnormal outlines assumed by the boundaries of certain deposits, when they are plotted down upon his map. In regions comparatively level the newer rocks as a rule are simply dropped down, more or less vertically, in comparison with the older strata. Sometimes a wedge-like mass, between a pair of faults, is let down, as a keystone might slip when an arch is strained outward; sometimes, by a series of parallel faults, slice after slice is dropped, like a set of steps, each one being displaced more than the last (Fig. 90). Occasionally the fault has been a gaping fissure, which is now filled up by fragments and shattered *débris*—a fault breccia, as it is called—separating the two comparatively unbroken masses, but its walls

are often in contact, and a peculiar grooving and polishing of the surfaces indicates that the one has slipped and slid over the other.*

Faults, of course, as a rule are more frequent and on a larger scale among the older strata, although a mass of rock of one of the later geological ages may be comparatively undisturbed in one country while it has been greatly displaced in another. In England the strata later than the Chalk are but slightly affected by subsequent disturbances. In these the greatest dislocation probably does not measure more than about a hundred feet vertical, and is commonly much less, while in the Alps beds of the same geological age have been uplifted to form mountain peaks, and have been broken and displaced, during this process, for thousands of feet. But among the older rocks of England the "throw" † of some of the faults is very large. By the Pennine fault, the western escarpment of the limestone hills, overlooking the Vale of Eden, is largely defined; its throw amounts in places to some 3000 feet, and that of a fault which occurs in the district near Sedbergh is estimated as hardly less than 5000 feet. But dislocations on a yet grander scale may be found in America. A fault in the Appalachians, though it produces no marked effect on the scenery, has so dislocated the rocks that, in the words of an observer, "on one side of a crack, over which a man can stride, the highest of Upper Silurian beds faces the lowest of Lower Silurian. But the Upper Silurian wall of this vast crack was 'denuded,' hewn away, and the place where it rose has been planed smooth, so that masses of grit, caught in the chinks while it was open, are cut through by the surface." This, according to the author quoted,‡ means a displacement of some 20,000 feet; but the process, no doubt, was gradual, and the surface all the time may have been kept, by continuous denudation, nearly at one level.

Some mention of joints has already been made. These are divisional surfaces produced by a very slight separation of rock masses, which, however, as has been said, are of great importance in determining the processes of denudation, and the outlines dominant in scenery, and sometimes, as planes of weakness, may facilitate the

* This structure is called (from a miner's name) slickensides; the surface commonly appears as if covered with a glaze; sometimes it may be seen on the faces of joints, especially if they are numerous or irregular, and no doubt results from oft-repeated slight movements, such, for example, as the tremors of earthquakes.

† The term applied to the amount of displacement estimated in a vertical direction, that in a lateral direction being called a "shift."

‡ Campbell, "Frost and Fire," ch. li.

formation of faults, whether in sedimentary or in igneous rocks. They may be attributed in both to one cause—contraction ; in the former the shrinking is probably due to the loss of water in drying ; in the latter to the loss of heat in cooling. The cracks which are formed in the muddy bed of a pond as the water evaporates are produced by the same cause as the great divisional planes which, in the Southeastern Tyrol, have defined the huge towers of the Drei Zinnen and of Monte Cristallo. The prismatic fissures in the sandstone lining a blast furnace have an origin similar to that of the columns in Fingal's Cave, in Staffa, or of the Giant's Causeway, in Antrim. The regularity of these prismatic joints indicates the uniformity of the strain to which the mass has been subjected ; that they are very commonly hexagonal is a consequence of the principle of least action, or, in other words, that Nature, in producing an effect, avoids the mistake so common among fussy folk, and does not expend more energy than is necessary. The perimeter of a hexagon, for any given area, is less than that of a square, and still less than that of an equilateral triangle ; so that when a six-sided prism is formed, the materials in parting offer the least resistance. In this figure also the greatest amount of a force acting toward its center is effective in producing rupture. It follows, from both these reasons, that when a mass is submitted to a uniform strain the cracks are likely to assume a hexagonal form. The columns thus shaped are divided by cross joints, which sometimes are curved, or exhibit a "cup and ball" structure. This is almost certainly another consequence of contraction, which, by acting uniformly throughout a mass of some thickness, leads to the formation of cracks more or less spherical in shape. These are commonest in glassy or compact igneous rocks, such as basalt. They may be on a very small scale, so that the spheroids are hardly

FIG. 115.
SPHEROIDS INSIDE A COLUMN, SHOWING INDEPENDENCE OF THESE AND THE SIDES (AUVERGNE).

FIG. 116.
SPHEROIDAL STRUCTURE IN A MASS OF VOLCANIC ASH (BURNTISLAND).

bigger than hemp seeds, as in certain volcanic glasses, or may be several inches, and even a yard or so in diameter. Generally each of these is traversed by more than one such divisional surface, so that it consists of a group of concentric shells. This structure is developed by the weathering of the rock, and thus the columns sometimes appear to be built up of flattened balls, like Dutch cheeses. Of this the well-known " Käse Grotte," near Bertrich Baden, in the Eifel, is an excellent example.

Another group of changes is rather of a chemical or physical

FIG. 117.—CHEESE GROTTO, NEAR BERTRICH BADEN.

character ; these are more or less molecular, and may be sometimes carried so far as to alter completely the condition of a rock. This is then called metamorphic, as already stated, because its constitution—its form, in the technical sense of that word—is no longer what it was originally. The three principal agents in these changes are water, pressure, and heat—sometimes one, sometimes another, taking the largest share of the work ; but where the alteration in structure and composition has been great, probably all have played a part, though not necessarily an equal part. Water, as already

described, is constantly at work, silently and secretly, in the heart of the rock, disintegrating and dissolving the more soluble constituents, taking up from one place to lay down in another, and at least aiding in the formation of fresh mineral substances. If we examine a thin slice of one of the harder limestones with a microscope, we see that the fragments of various organisms, of which it is largely composed, are cemented by crystalline carbonate of lime. This mineral must have been deposited by the action of water since the rock first was accumulated, in much the same way as it is precipitated in the stalactites in the caves of Cheddar, or in the tufas at the cascades of Tivoli. Sometimes also we find that the fragments themselves are beginning to undergo a change; the structure characteristic of the organisms is beginning to disappear, and is being replaced by that of the mineral. In other cases the original substance of an organism has wholly vanished, and in its stead we find an exact model formed of some other material. For instance, carbonate of lime may be converted into phosphate of lime, or it may be replaced by silica, as in the Greensand of Blackdown, the flints of the Chalk, or the cherts of the Derbyshire limestones. Sometimes also, in the case of the last named, the original organisms have been first sealed up in a mass of siliceous material, and have been then dissolved away, so as to leave an exact cast in chert both of their outer form and of their inner cavities.

Processes somewhat analogous lead to the concentration of particular substances round fragments, either of minerals or of organisms, which play the part of a nucleus. Thus concretions, as they are called, are formed. These are sometimes small, like oolitic or pisolitic structure (usually restricted to calcareous rocks), in which little balls vary from the size of the eggs in the "hardroe" of a herring to that of a pea; but they are sometimes large, and the longest diameter may occasionally exceed a yard. They are frequently about the size of an apple, or of a potato, often being smooth externally, and elliptical in form, so that one of them might be mistaken, at a hasty glance, for a pebble. Instances of such concretions are afforded by the "cement stones," common in shales and clays of different geological ages, which, on being broken open, are generally found to contain a fossil; by the globular concretions, also calcareous, in the Magnesian Limestones of Durham; and by the "penny stones," or nodules rich in carbonate of iron, which are found in the clays among the Coal Measures. In the last also a fossil usually forms the nucleus, as well as in the so-called coprolites.

These are all examples of mineral concentration, resulting often from chemical action which is initiated by the decomposition of organic substances, and is continued in accordance with the principle that in Nature "like seeks like." It is a consequence of the action of water; it is accelerated by a rise in temperature; it is indirectly facilitated by the action of pressure, which increases the solvent and destructive power of the fluid, and thus, by taking one mineral to pieces, prepares the way for the formation of another.

But pressure alone, and heat alone, also bring about the alteration of rocks. The one agent, though producing, as has been shown, planes of division, promotes a molecular union and consolidates the intervening particles. Of this experimental demonstration can be given in certain cases; by heavy pressure metals can be welded, powdered graphite or "blacklead" can be squeezed into solid blocks; and by a pressure of some 950 hundredweight to the square inch, peat can be converted into a substance resembling coal. The other agent, heat, ultimately melts the materials of rocks, but it also produces considerable mineral changes at temperatures below that of fusion. The first stage is that of simple induration, as in the making of bricks and the baking of pottery; but at higher temperatures, or with suitable constituents, more marked mineral changes begin. One of the most conspicuous is afforded by pieces of glass which have been raised to a high temperature—perhaps just sufficient to soften them without actual melting. After slow cooling the glass is found to have become an opaque white substance, consisting of small needle-like crystals thickly crowded together, the grouping of which often appears to have been influenced by the bounding surfaces. Glass may be also affected in a similar way by exposing it to the combined actions of heat, pressure, and water. Professor Daubrée placed a piece of it in a strong iron vessel full of water, which was then securely closed, and subjected for several days to the heat of a furnace. On examination some of the glass was found to have been dissolved, and small crystals of minerals formed from it were lying loose in the water; the remainder was crowded with small crystallized minerals, as in the case of devitrification already described. The effect of heat in the presence of water, and under a certain amount of pressure, may be often studied in the neighborhood of intrusive igneous rocks. Small masses produce but slight effects on the sedimentary materials; sandstones are hardened, limestones seem slightly more compact, clays are converted into a kind of natural brick or porcelain. But large masses, especially of

granite,* produce changes which may be traced for some hundreds of yards. As we proceed toward the intruder, the limestones gradually become coarsely crystalline, all traces of fossils disappearing, and new minerals are developed, the latter coming from a slight amount of muddy sediment which is present in all but the very purest limestones. But the change is most marked in clayey rocks, such as shales or slates. In these various aluminous silicates are formed, one of the most characteristic being a peculiar brown mica. These minerals, at first small and ill defined, become larger and better developed as the intruding mass is approached. Moreover, granules of quartz, if originally present, are enlarged, and new grains are formed ; at last the rock loses all resemblance to a sediment, and becomes a crystallized mass, hard and solid.

But in rocks of a suitable character many changes are probably due to the action of water and pressure, with little, if any, rise of temperature. Among these may be included a kind of devitrification frequently occurring in certain ancient lavas which are believed (with good reason) to have been formerly glassy, and the conversion of rocks which once consisted mainly of olivine into the material called serpentine, so largely employed for ornamental purposes. In the last case the change is one of hydration—that is, caused by the entry of water into chemical combination with certain of the constituents.

A rock is called metamorphic when these changes have been carried so far that its original character is ascertained with great difficulty. Many such rocks exhibit a peculiar structure called foliation. This term implies a distinct tendency to a parallelism in one or more of the mineral constituents. All such rocks are obviously crystalline, and to them alone the name schist is properly applied. In some cases not only is this structure exhibited, but also certain of the component minerals are more or less aggregated so as to form bands. The origin of the crystalline schists, with which the gneisses may be included, is a very difficult question, which has been the subject of many controversies. That not a few schists were orginally sediments, and have been subsequently altered, may be regarded as certain. The mud has become a mica-schist, the limestone a marble or a calc-schist, the sandstone a quartzite or a quartz-schist ; but there are other schists, the origin of which

* It must be remembered that when an igneous rock is coarsely crystalline, this is an indication of its having cooled slowly, and at a considerable depth from the surface—*i. e.*, under a fair amount of pressure.

must have been different. A foliated structure may result from the crushing of an igneous rock, which has been followed by a certain amount of mineral reconstitution.* This seems to take place in rocks already crystalline, more readily than in ordinary sediments. In this way certain gneisses and schists have been produced. Other rocks may have been foliated from the very first, and the structure may be the result of slow movements as the mass gradually became cool and solidified.†

Mineral veins may be mentioned in connection with this subject. An explanation of their history involves many difficulties, and cannot receive detailed treatment in a work such as this. So since, notwithstanding their great commercial importance, they affect but small portions of the earth's crust, they must receive only a passing notice. A mineral vein appears generally to have originated in a fissure. This has been sealed up, more or less completely, by a mass of minerals, which sometimes, as it were, impregnate the adjacent rock. The veins may contain few or several minerals, one or more of these commonly being a metal or a metallic ore, but no hard and fast line can be drawn between a metalliferous and any other vein. The minerals appear to have been deposited by water, and sometimes to have been derived from the neighboring rock, sometimes to have been brought from below. It may be inferred that the latter is of frequent occurrence from the mode in which the adjacent rock is affected and impregnated.‡ In many cases the water probably was at a high temperature. For instance, at Steamboat Springs, Nev., and Sulphur Bank, Cal., § fissures are now ejecting steam or hot water, and are being gradually filled with silica (first colloid, then crystalline) and various other minerals, among them sulphides of iron and of mercury, and even gold. Thus the formation of a mineral vein often indicates a stage, generally an expiring one, in volcanic action. They are striking illustrations of the changes which can be wrought in rocks by the action of subterranean water at a high temperature. ‖

* There is no proof that a banded structure can be produced in this way.

† This case is analogous to the formation of the streaky structure seen in certain slags and vitreous lavas.

‡ The nature of the rock appears sometimes to have an effect on the mineral deposited, for it is noticed that if a fissure traverses two kinds of rock there is a corresponding change in the ore; differences also in the temperature of the water will determine the order in which it deposits particular substances.

§ A. Phillips, *Quarterly Journal of the Geological Society*, vol. xxxv. 1879, p. 390.

‖ See the notice of mineral springs, p. 117.

Thus, by a variety of processes, mechanical movements and molecular changes have produced effects in the crust of the earth, as far down at least as man has been able to submit any part of it to examination. To what depth they may be continued he has no means of ascertaining. Wherever air or water can penetrate, there chemical change is almost certain to occur, there the antagonistic but compensatory processes of disintegration and of combination are sure to carry on their task of destroying and of building. They began it when this planet first gathered into solid form, as

> Ilion like a mist rose into towers ;

they will continue it till that far-off day when, in consequence of the dissipation of energy, "the sun itself shall die," and the earth, airless and waterless, shall be rigid in the cold of outer space.

Part IV.

THE STORY OF PAST AGES.

CHAPTER I.

METEORS AND THE EARTH'S BEGINNING.

In the preceding chapters an outline is given of the processes which obviously are still at work in changing the surface of our planet and in modifying the structure of its crust. It has been our endeavor to describe and make clear, as far as our limits permitted, the facts which, on an inductive study, establish those principles of geology in accordance with which the earth's present contours and the existing distribution of land and water are explained, and its physical geography in past epochs is inferred from the testimony of the rocks themselves. Remote as these epochs may be, imperfect as their record too often is, we may confidently reason as to the significance and interpretation of their character in reliance on the general uniformity of Nature's operations—viz., that similar effects are the results of similar causes ; or, in other words, that the marks which at the present time denote the action of the stream, the wave, or the glacier, are indicative of the same forces in every age of the globe, and that the structure which now characterizes a particular group of organisms is a proof that a similar group was in existence, at the geological epoch, in the rocks of which this structure has been detected. If a pebble of a certain shape and weight is now moved by a current of a known velocity, if fragments of a certain kind are now ejected and accumulated by volcanic explosions, if some structures are characteristic of rocks which have been deposited by water, and others of rocks which have become solid from a state of fusion—if, for example, no hardened sediment bears any real resemblance to a basalt, and no limestone could possibly be ejected as a stream of lava from a volcano—we have no hesitation in asserting that the same conclusions must hold good in any geological epoch, so long as the conditions on this planet were practically identical with those which still exist. It is probable, indeed, that as we retrace the history of the globe these conditions will gradually become less like those which still prevail, but the variation even then will be in degree rather than in kind. The

changes will still be gradual in the main, even if they be quicker than at present; they will be of like nature, in all probability, so long as the earth may be regarded as a solid body, and certainly during all the time since it has become fit to be inhabited by living creatures. Toward the beginning of this period we must walk warily, even in following the inductive path ; and in regard to that which was anterior to it we must argue from analogy, and so must venture cautiously on hypothesis. In preparing to deal with this far-off epoch the geologist must lift his eyes from the ground beneath his feet, and look upward to the orbs of heaven and the star-studded region of the sky. He must be content to seek help from the student of physics and the astronomer.

We shall endeavor in the following chapters to tell, in its broad outlines, the story of the earth, and to indicate the steps—if such a term be permissible—by which it was prepared to be the scene of the drama of man's life. "All the world's a stage," but this particular theater has been long in building. The tragedy or the comedy of human life is in itself only a *dénouement* up to which the ages of the past have been gradually leading. We might tell the tale, as geologists have deciphered its record, by working back from the present to the past, but the usual historical method is far preferable. "In the beginning" is a natural opening for every story, and we shall endeavor, in this rough sketch, to trace our planet's course along the corridors of time, and to commence in that dim and distant epoch when it might be said, in the words where poetry joins hands with science, that "the earth was without form and void."

By day the sun warms and illuminates this planet, by night the clear sky is studded thick with "patines of bright gold" ; these, too, are suns ; these may be each one the center of a planetary system. Across the "black concave," like drops of condensed light, the "shooting stars," as they are poetically called by simple folk, the meteors, as they are named in the tongue of science, dart or glide through the darkness. At intervals more rare the comet gleams like a pale torch among the brighter sparkles, and the nebulæ seem as clouds faintly luminous in the awful darkness of outer space. Comets, nebulæ, meteors, suns—what light can they throw on that beginning of which man inquires hardly less curiously than of the end which he tries to forecast for himself, his race, and the world? Whence and whither?—that is the question which some occult impulse drives us all to ask of our environment. To

the latter clause science cannot reply, to the former it can return only a halting and uncertain answer; but, since "the oracles are dumb," if this fail to satisfy us, we shall find no other response.

With such meteors as fall upon the earth the chemist and mineralogist has no more difficulty in dealing than with any other rock fragment. He finds them to be masses, more or less crystalline, of minerals already well known by his researches among terrestrial substances. The great majority consist mainly either of pure iron or of some admixture of this with ferro-magnesian silicates, among which the mineral olivine is the most abundant. With these small quantities of other well-known elements are present, as, for example, chromium, nickel, aluminium, calcium, and carbon.* All these occur in terrestrial bodies; from the study of meteorites no new element has been obtained. Iron, which is so abundant in them, is a metal with which we are all familiar; it is present, occasionally in considerable quantity, in almost every igneous rock, and some geologists are of opinion that certain dyke-like masses of its oxide have had an eruptive origin. Those meteors which consist chiefly of olivine correspond precisely with a well-known rock, certainly igneous, called peridotite;† this rock, it is interesting to note, has been hardly ever ejected as scoria, perhaps has never formed a lava flow. It appears to represent some rather deep-seated material. Native iron also, though it has been discovered in lava (basaltic), sometimes in masses of considerable size, generally occurs in such cases as lumps, which seem as if they had been caught up and transported by the rock in which they have been discovered.

The meteorites, then, consist of the same materials as the earth's crust, and may be regarded as samples which are representative of its more deep-seated, rather than of its most superficial, portion. But these meteorites appear to abound throughout all that portion of space which is traversed by our globe. Besides the two great "swarms" which, as astronomers now believe, circle about the sun in huge elliptical orbits, one of which is traversed by the earth about the middle of August, and the other early in November, scarce a night passes without some solitary travelers from this unnumbered horde of celestial vagrants crossing the track of the earth. Moving in obedience to the same laws as our planet, though we know not in what orbits, they dash through its atmosphere at a

*This has been found crystallized in two forms, the most recently discovered in meteors being the diamond.

†This, as already said, is more commonly met with in its altered form, "serpentine."

rate which "is perhaps one hundred times that of a rifle bullet." Previous to that they had circled in the emptiness of space "for thousands, perhaps millions, of years without let or hindrance, but the supreme moment arrives, and the meteor perishes in a streak of splendor." By friction with air they are intensely heated, raised to a temperature so high that they glow with incandescent light as they dart across the sky; sometimes they are dissipated into glowing dust or luminous vapor, which marks for a few moments their path through the atmosphere before the darkness once more swallows it up; sometimes they vanish again into space, deflected into a new path, and are no more seen; sometimes they are caught by the attraction of the huge mass of the earth and fall upon its surface. There is no reason to suppose that these migratory flights of meteors are restricted just to that portion of space in which the earth performs its annual journey; the whole solar system may well be permeated with this dust of worlds. Many astronomers believe that meteors are showering down upon the sun in a constant and increasing hail, and maintain, like fuel, the light and heat of the central orb. If this be so, and it is probably true, we might have argued, that since the center of our system is not stationary, but the sun itself is ever speeding onward, space also should be similarly filled. But without entering upon this wide question, even if we consider the meteors of which we have cognizance to be denizens of our own system, we are justified in regarding them as "chips from Nature's workshop," and, as such, indicative that the materials which have been employed in the making of worlds are not unfairly represented in our own—in other words, that any hints which may be supplied by the study of the members of the solar system may be utilized in explaining the composition and history of our own globe.

If we read the story of the sun, we shall find in it many facts which strongly support this inference, and are illustrations of the probable constitution of the earth. The sun, as astronomers are now generally agreed, consists of a huge mass of matter, surrounded by a luminous atmosphere. The inner mass is at a high temperature, but the outer zone is so much hotter, is quivering with vibrations so intense, that the inner orb seems dark in comparison with it, and chemical combination between its constituent elements is impossible. The sun, as a whole, "is infinitely hotter than a Bessemer converter or a Siemens furnace." Of late years several skillful observers have undertaken comparative studies of the spectra of telluric elements and of the sun. Perhaps the latest

and most complete are those by Professor H. A. Rowland, the result of whose researches may be thus briefly summarized: "Practically all the known elements, with the exception of a few very rare ones, and one or two gases, have been compared with the solar spectrum. . . Some thirty-six elements have thus been identified in the sun, the cases of eight more are considered doubtful, and fifteen are not represented in the solar spectrum. Of the last class Professor Rowland points out that most of them have

FIG. 118.—SURFACE OF THE SUN, AS SHOWN BY A SOLAR SPOT.

few, if any, strong lines within the limit of the solar spectrum, when the arc spectrum, which he employed, is used. Some good reason, he adds, generally appears for their absence from the solar spectrum. Of course there is little evidence of their absence from the sun itself; were the whole earth heated to the temperature of the sun, its spectrum would probably resemble that of the sun very closely." * We learn, then, from students of solar physics that in this huge mass materials similar to those of the earth are collected, though not necessarily in the same proportion, only in it they are glowing with an intense heat, which, at any rate in the visible part, is so great as to prevent chemical combination—heat which sur-

* Professor Rowland, "Johns Hopkins University Circular," No. 85, from summary in "Yearbook of Science" for 1891.

passes even that of fused platinum, and perhaps the highest temperature obtainable in our laboratories.

From the sun, the center of this system, astronomers have turned their spectroscopes upon the stars—bodies, certainly, no less vast—some of which, as it has been discovered, burst forth at times into a brighter blaze. In the results obtained by their researches differences have been observed which have been used for purposes of classification. In the first group of these far-off suns are placed intensely white stars, like Sirius and Vega: Comparatively few lines are exhibited by their spectra, but those of hydrogen are very strong, so this gas evidently forms a large part of their atmospheres, as in that of our sun; the lines of calcium and magnesium also have been detected, but they are faint. The spectra of the second group of stars closely resemble that of the sun. "The chief hydrogen lines are conspicuous, but many metallic lines are coming strongly out."* The third type exhibits many metallic lines, but hydrogen is absent. This evidence, so far as it goes, indicates that even in the immensity of space, through which these thousand myriads of suns are moving, doubtless in obedience to the same laws that regulate our solar system, there is a general community of material. But this is not quite all. The comets, attenuated as is their substance, inappreciably slight as is their mass, consist apparently of hydrogen, with various compounds of carbon, possibly chlorine, and some other terrestrial substances. The spectroscope also has been turned on the nebulæ, those clouds of glowing gas which, on a clear night, gleam ghostly in the blackness of the star-studded sky. "It is believed that some of these are sunk in space to such an appalling distance that the light takes centuries before it reaches the earth. We see these nebulæ, not as they are now, but as they were centuries ago." Yet, so far as information at present goes, the lines in the spectra of these mysterious star clouds have revealed the presence of familiar substances, such as hydrogen and nitrogen, though there are also some lines which cannot be identified with known elements. It is possible, of course, that every elemental substance is only a form or mode of manifestation of some one common matter, so that in the apparent diversity of inorganic nature there may be a latent unity. But this is a question which lies outside our immediate purpose, one concerning which too little is at present known to make it of any practical value for this

*Sir R. S. Ball, "The Story of the Heavens," ch. xxii.

inquiry. So it follows as one result of these investigations that worlds, at any rate in our solar system, are constructed of the same materials, though these are not necessarily aggregated always in the same proportion. In some the heavier, in some the lighter, substances may predominate; elements may exist in some which are absent in others; in all cases obviously our knowledge only extends to such constituents as are present in these bodies at a temperature so high as to be luminous enough to affect a spectroscope, and it is little more than skin deep in the case of the earth,

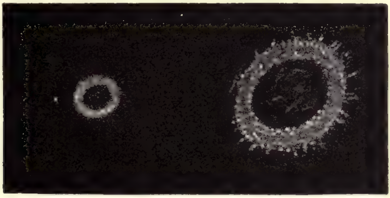


FIG. 119.—THE ANNULAR NEBULA IN LYRA.

which is our standard of comparison. But so far as our knowledge extends, it is very favorable to the idea that sun, planets, and moons, in this system, have had a common origin, have been developed from some primary condition of a mass of materials which have gradually become what they are at present. The statement very likely might be extended to all stellar space. We know of no reason why it should not be full of worlds and systems, in various phases of development, in every stage from birth to death—if such terms be applicable, from the condition of a nebula to that of the satellite of this earth.

Is it, then, possible to speculate, to form any reasonable hypothesis, as to the initial condition of our earth and of the solar system to which it belongs? This has been attempted, and the hypothesis at any rate has the merit of comparative simplicity. It may be briefly stated as follows: Suppose a portion of space to have been formerly occupied by an enormous body of matter, consisting mainly or wholly of gas at a high temperature—in other words, a vast nebula, like that which gleams below the Belt of Orion. Suppose that this body, as seems to be the case with some of the nebulæ, were rotating about an axis. "The hot mass will cool and so contract. Contraction will make it rotate faster. You are all

familiar with the domestic experiment of twirling a mop. At first no results follows, but as you spin it faster and faster the water at last begins to fly off. In the same way the nebulous ball will at last spin at such a rate that it can no longer hold together, and a ring will be thrown off round its equator." This, of course, will be at the end of a gradual deformation. If the original mass were a sphere, this, as the rate of rotation increased, would become more and more spheroidal in outline, the polar diameter diminishing as the equatorial increased, until at last the protuberant part became separated from the main mass. "The ring will at first spin round in the same direction as the ball it has left. But the ring cannot hold together." It, too, is losing heat, and then soon becomes exposed to other strains than that caused by its rotation. "It breaks up and collects into a ball. This ball revolves in the same direction as the nebula of which it originally formed a part, and at the same time rotates in the same direction around an axis parallel to the axis of rotation of the nebula.

"Further contraction will cause another ring to be thrown off, which will likewise collect into a ball. So in the end we shall have a number of balls all revolving in the same plane about a common center, and rotating all in the same direction about axes perpendicular to that plane, and in the center a large mass still in a gaseous and heated state. These balls, being small, will cool and condense into planets; the central mass, being large, will retain its heat much longer, and will form a sun. It may happen that some of the balls will, as they contract, throw off rings, which will collect into balls, and so we shall get moons revolving about some of the planets."

"This is very nearly the constitution of our solar system. With one, or perhaps a few, singular exceptions among the outermost bodies, the planets and moons all move round the sun in the same direction and in planes inclined to one another at small angles, and all rotate upon axes nearly perpendicular to their common plane of revolution in the same direction as they revolve."

"The probability that such an arrangement could have been brought about by chance is so infinitesimally small that we are driven to the belief that it is a necessary consequence of the way in which the solar system came into existence. The facts point to some common origin for all the members of the system, and to some common scheme, according to which the system was grown into its present shape; assuming, of course, that it has reached its present state by some process of natural evolution, an assumption to which

analogy leads. The nebular hypothesis furnishes us with such a scheme and such an origin." *

This hypothesis was first stated explicitly about the middle of the last century by the great German philosopher Immanuel Kant; but it was advanced independently and in a more systematic and developed form by Laplace shortly before the end of the same century. Additional probability was lent to it by an ingenious experimental illustration, devised by a Belgian *savant*, M. Plateau. By means of a mechanical contrivance he succeeded in imparting a rotation to a ball of oil, as it floated in a mixture of water and spirits of wine, which was of exactly the same specific gravity, and he was able to increase at pleasure the velocity of rotation. As this was done, the globe of oil gradually flattened at the poles and bulged at the equator. Then, as it was made to whirl round yet more rapidly, it threw off a ring, which presently was followed by another and another. Each of these in turn suddenly broke up and assumed the form of a little ball, rotating on its axis and revolving in an orbit about the central globe. Here obviously the fracture was due to the expansion. The precise cause, no doubt, which brought about the result in Plateau's experiment was different from that which is supposed to have occurred in Nature. The strain in the one is caused by increasing the velocity of rotation, in the other by contraction through loss of heat; still the principle is similar, and forces opposite in sign, as they would be called by mathematicians, often produce results which are alike in kind. So close is the general resemblance presented by the experiment that "anyone looking at it might well fancy it was an exact representation of the solar system." †

Let us follow rather further the history of one of these planetary masses detached from the central sun. It is composed of somewhat similar material, and even at the moment of severance probably is still in a more or less nebulous condition, and at a very high temperature. As it proceeds on its journey heat is lost by radiation into space; the temperature of the whole mass falls, but the outer layers are especially chilled. For a considerable while there will be an up and down movement in the orb—the cooler matter descending from the exterior, the hotter ascending from the interior. By

* The above extracts are taken from Professor A. H. Green's lucid and pleasantly written little book, the "Birth and Growth of Worlds," p. 42.

† Réclus. "The Earth," part i. ch. iii.

this means, in process of time, a kind of stratification will be produced in the mass, the lighter and more readily vaporized substances working their way toward the exterior, the heavier and those which most readily solidify accumulating at the interior.* This transference and selective ordering will continue so long as the materials of the planet remain in a vaporous or even in a thoroughly liquid condition. But as time goes on internal movements and relative displacements will become more difficult. The outer surface of the globe will begin to crust over, and the condition of the interior—whether simultaneously or not we cannot say—will be modified by another cause. Here, obviously, the condensation of the mass produces a tremendous pressure. The high temperature of the interior tends to drive its molecules apart one from another, but the weight of the outer layers tends to pack them closer and closer, and thus to produce a solid nucleus. The two tendencies are antagonistic, and our knowledge does not yet enable us to determine which of the two will prevail.

To this point, however, we must refer again in considering the question of the probable condition of the earth's interior. It may suffice for the present to say that some while after the earth had commenced its journey as an independent planet, but perhaps not long after its own satellite had been detached, its outer part must have been gradually covered with a crust. Assuming this to have been composed of such materials as are now ejected from volcanoes, it would contract, though perhaps not much, in cooling.† But this change in volume would cause strains, and the new-formed crust would be rent and shattered. As it would be heavier than the fluid on which it had formed, these fragments might be engulfed, and perhaps again melted down; but as the fluid would be already in a viscous condition, and the difference in specific gravity would not be great, the fragments very probably would continue to float, and after a time would again "freeze" together. The description given by Professor Dana of one of the lakes of lava in the crater of Kilauea

* A stratified arrangement, according to Mr. Lockyer, is exhibited by the sun. The planets exterior to the orbit of the earth are composed of materials lighter than it; the two nearer to the sun are rather heavier in proportion. Even in the earth itself the atmosphere, the water, and the inner mass come in like order.

† It is not every substance (as is well known) that contracts in cooling, and the amount of contraction even of such familiar materials as basalt or trachyte is not very accurately determined, but, as a general rule, it may be assumed that the igneous rocks occupy less space in a solid than in a liquid form.

may serve to represent, on a small scale, a process which at first would be very general over large areas of the earth's surface: *

"Although mostly crusted over [the lake] showed the red fires in a few long crossing lines (fissures), and in three to five open places, halfway under the overhanging rock of the margin, where the lavas were dashing up in spray, and splashing noisily with seemingly the liquidity of water. Now and then the fireplaces widened out toward the interior of the lake, breaking up the crust, and consuming it by fusion. . . Although relatively so quiet, the mobility of the brilliant splashing lavas made it an intensely interesting sight. Occasionally the red fissures widened by a fusing of the sides as the crust near by heaved and the lavas flowed over the surface. It was evident from the cooled streams outside that now and then more forcible movements take place, followed by outflows over the margin, when the whole lake is in action."

But at first the strains of the shrinking mass and the pressure of the imprisoned vapors would not be the only disturbers of the equilibrium of the crust. The part immediately below it, whatever might be the state of the central portion of the globe, would be fluid—an incandescent ocean many miles, at least, in depth, just frozen over at the surface. This liquid mass would be affected by the attraction of the moon (if it were already detached) and of the sun, which at that time, possibly, might be augmented in bulk by the matter which is now condensed into Mercury (supposing Venus to have begun an independent journey). Round and round the earth a great tidal wave would travel in this molten sea, and the crust would be thrown again and again into a state of strain, by which it might be repeatedly ruptured until it had become sufficiently thick to offer an adequate resistance to these recurrent disturbances.

The temperature at which the crust would begin to form would probably be something like 2000° F. This, as was stated in a former chapter,† is a rough inference from observations made on lava streams as they are cooling, and on certain rocks as they are melted artificially. But since water, under ordinary conditions, boils at 212° F., its vapor could not condense and remain upon the crust until the latter had cooled down to very much below even a dull red heat. At that time the atmosphere would be greatly heated; neither ocean nor lake nor river could exist. The crust

* "Characteristics of Volcanoes," p. 113. † P. 243.

must have long ceased to glow; it must have solidified to a moderate depth at least (though, no doubt, substances like lava are bad conductors) before the watery envelope could begin to form. If so, the crust itself must have solidified under conditions materially different from those of a lava stream at the present day; for not only is crystallization affected by pressure, but also radiation would be then comparatively slow, because the atmosphere would differ much less in temperature from the solidifying rock than the air now does from the surface of the lava stream. The crust would probably be formed in all cases at a temperature above that of "white heat," and it would change slowly down through the various grades of color till the natural tint of the constituent rock was assumed. Yet, even then, water at first would not be able to rest upon it, but if by some chance the vapor in the atmosphere were locally condensed, the drops of boiling rain would be rejected hissing from the uncongenial surface. But what would this mean? If the present ocean were converted into vapor, the weight of the atmosphere would be augmented by that of a shell of water of the area of the globe and two miles in thickness; or, in other words, the atmospheric pressure would be then about 350 times its present amount.* If so, even a lava flow would consolidate under a pressure equivalent to that of some 4000 feet of average rock; † it would be in a condition more like that of an intrusive "sill" nearly three-quarters of a mile below the surface, but with this difference, that the process of cooling would be slower, because the temperature of the atmosphere would be far higher than that of the earth is now, and for long has been, at this depth. Whether any relics of this primeval crust can still be recognized is a matter on which very different opinions are entertained by geologists; the majority, probably, would answer in the negative. But this subject can be more appropriately noticed in a future chapter. For the present it may suffice to indicate the general character of the process of consolidation, and to emphasize the fact that it occurred under circumstances materially different from those which can have existed in the immense period during which any form of life has been present on the earth. No doubt a universal negative is a dangerous thing; and a man has endured for a time the environ-

* The increased atmospheric pressure would obviously raise the boiling point of water above 212° F., and so allow it to condense at a higher temperature than it now can do, but this would not affect the general argument used above.

† See the author's "Rede Lecture" for 1892, printed in *Nature*, vol. xlvi. p. 180.

ment of an oven hot enough to cook a beefsteak; still, it may be affirmed that the earth remained void of life so long as the temperature of its crust exceeded that at which water now boils at the sea level.

Whatever might be the condition of the great interior mass of the earth—whether it continued liquid, at least for some ages longer, or whether, as is considered more probable by many eminent physicists, solidification commenced at the center, in consequence of the great pressure to which the inmost part was subjected, and extended outward till it was met, so to say, by the thickening skin—we may assume an original liquidity of the surface, and pass on to inquire what modification this would undergo in the process of cooling. So many matters which are essential factors in the investigation are so little known at present that all inferences must be regarded as hardly more than conjectures and provisional in character; but even an hypothesis has its advantages when the data are insufficient for the construction of a theory, since it serves to direct the thoughts and suggest the lines of an inquiry, and brings to light principles of which, in any case, some account must be taken. The spots which occasionally darken the sun's face indicate that perfect uniformity does not prevail even under conditions which must have long ceased on our globe at the epoch now under consideration, and that not inconsiderable areas of the solar envelope are in a state different from that of the rest. So, in the case of the earth, when it first solidified, there is no evidence that every part of its vaporous envelope was in a perfectly uniform condition, or the surface beneath it completely homogeneous in composition and in state. Some parts of the exterior, owing to unknown reasons, may have begun to solidify slightly in advance of others; and even after a crust had formed over the whole, this may not have been in every part equally strong or equally thick. When the atmosphere had reached its present condition, if not before, the heat emitted by the sun must have had more effect in equatorial than in polar regions, so that the crust would stiffen and thicken rather more rapidly near to the latter than near to the former. Professor Daubrée has shown by some interesting experiments that if, when a globular body contracts, its crust be less flexible in some parts than in others, its regular spherical form is not retained, but a deformation takes place, which depends on the difference in rigidity of the material. He employed in his experiments a common material and a familiar apparatus. Every-

one knows those colored balls of india rubber which are distended with air or with gas, and are of various sizes, from about five to ten inches or more in diameter. The child's toy was pressed into the service of science. Professor Daubrée took some balls of the larger size, such as are commonly sold in Paris, and placed on their exterior a partial coat of paint, which had been carefully prepared so as to adhere perfectly during any change of volume of the ball. This paint was applied, not irregularly, but in definite patterns, to several balls. On one it formed a broad strip—a kind of girdle—about the equator; on another it was arranged in zones extending from pole to pole, corresponding in shape with the spaces between circles of longitude, and about 45° in width; on a third no paint was placed. Some of the air was then allowed to escape. The india rubber of course contracted. In the last case this produced a wrinkling of the surface without any approach to regularity, but obviously influenced by accidental results of the processes adopted in making the ball, such as the deposit of a little more sulphur in one part than in another. But in the other two cases—not to mention instances where the paint was disposed in less simple patterns—the effects were very remarkable. The uncovered portion of the india rubber contracted more than that which had been stiffened by paint. The latter accordingly bulged up, so as to form a low mound, in section like a very flattened arch, and across this, perpendicular to its sides, ran a series of many small, similarly shaped undulations. In every instance the part covered by paint rose like a low island above the level of the rest, and was always traversed by wrinkles, which ran at right angles to its external boundary.

These experiments indicate that if, at any early period of the earth's history, while the crust was still comparatively thin and flexible, and the loss of heat and consequent contraction were correspondingly rapid, certain parts had become distinctly more indurated than others—it matters not from what cause—this fact would bring about a marked deformation of the surface which bore a direct relation to the disposition of the harder and the more flexible parts. The one would be upheaved as continental masses, the other would become receptacles for the ocean. In these land masses the rocks at first would not be sharply folded or violently displaced, but rather would be bent into gently undulating curves. It is a fact, which seems to be not without significance, that this structure is very characteristic of certain rocks which, with good reason, may be considered to be some of the oldest known. To this point, however,

we must again recur; for the present it suffices to bear in mind that any irregularity in the first formed crust not only must produce an immediate effect, but also must influence the result of all further contraction. Moreover, when once the sea had covered portions of the crust, these would radiate heat less rapidly than the parts in direct contact with the atmosphere. Under the former the crust would increase more slowly in thickness, and thus continue to be more flexible than under the latter or land parts. Strain in the one case might result in gradual and continuous flexure, tending to augment and deepen the depression already formed; in the other it might be resisted for a time, with the ultimate consequence of a more sudden yielding, accompanied by crushing, faulting, and all the more conspicuous signs of disturbance. But we must abstain from following any further this line of speculation; for the processes of Nature already described—the results of denudation and deposition—also cannot fail to produce important modifications in the strength and structure of the crust, and the subject speedily becomes so complicated that, with our present knowledge, we must rest content with calling attention to causes which cannot fail to have produced effects, and with keeping careful watch for any hints which may be furnished by the special study of particular districts.

But, it may be asked, is there any proof beyond the analogy of other celestial bodies that this earth was ever so intensely heated that its whole surface may have resembled an ocean of lava? Does the globe itself testify in any way to its former condition? Passing by these analogies, and the fact that the spheroidal shape of our planet suggests an original flexibility, which is more naturally ascribed to heat than to any other cause, we may seek an answer to the question from the earth itself. If it has cooled down to its present condition from incandescence, the interior should be still very hot. Direct experiment will not, of course, take us very far, but if all the evidence which can be obtained points in one direction, and if the conclusion which it suggests can be supported by indirect reasoning, a well-grounded confidence may be felt in the accuracy of our induction.

Let us briefly review this evidence. In the first place the temperature of water from deep-seated springs or wells is barely or not at all affected by the diurnal or annual variation of temperature. In the well of Grenelle the water, which rises from a depth of more than 1300 feet below the surface, is at the same temperature in January as in July, and at any place the water from a deep well is warmer than

that from a shallow one. Borings have been made and shafts have been sunk into the earth's crust to a depth frequently of more than a thousand feet, occasionally of more than two thousand, and in one or two cases exceeding three thousand. The Mont Cenis tunnel, at its greatest distance from the surface of the ground, is 5280 feet below the crest of the Alps, and the St. Gothard tunnel in like manner reaches a distance of 5578 feet; that is to say, opportunities have been afforded of ascertaining experimentally the temperature of the crust of the earth down to a depth of about a mile. In all these cases the result is the same, that after reaching a distance from the surface,* at which the fluctuations in temperature—whether diurnal or annual—due to the increase or decrease of the heat received from the sun, are no longer perceptible (generally about sixty feet beneath the surface), the temperature invariably increases with the depth. The rate of increase is subject to considerable variation; it is affected, as might be expected, by the conductivity of the rocks, by their mineral composition and arrangement, and by local circumstances not always easy to determine. For instance, it may be as low as 1° F. for every 82 feet of descent, on the average,† or as rapid as 1° F. for 34 feet;‡ but the great majority of the observations give averages not far away from 1° F. to 60 feet. The Committee of the British Association after discussing a large number of observations came to the conclusion that 1° F. in 64 feet was a fairly safe average.§ So for a certain, though a limited, distance the crust of the earth evidently becomes hotter as the depth from the surface increases, and the rise is such as might be expected if the inner mass were at a high temperature and losing heat by radiation.

Another consideration of a more general character points to the same conclusion. If the earth be regarded as consisting of a series of concentric shells, each of these has to support the weight of all those above it. Pressure accordingly increases in proportion with the distance from the surface. Every deep coal mine affords proof of the truth of this statement, for when some part of a seam has been

* The depth of the Sperenberg boring, chiefly in rock salt, at which observations were made was 3492 feet; that of a coal pit at St. André du Poirier is 3084 feet.

† This is in the St. Gothard tunnel, and the increase in the Cenis tunnel is only 1° F. in 79 feet. In a pit at Dukinfield (2700 feet) it is 1° F. in 72 feet; in another at Wigan (2424 feet) it is 1° F. in 79 feet; but in one of the pits at St. André du Poirier (2952 feet) it does not exceed 1° F. in 116 feet—a most exceptional slowness.

‡ A mine at Weardale, in Northumberland.

§ See "British Association Report," 1881, p. 88.

worked away, the floor of the excavation bulges up, the roof "sags" down, and the walls begin to be crushed by the tremendous pressure of the overlying strata. If this is so great that in a mine at Dukinfield, 2500 feet below the surface, a brick arch, four feet in thickness and of no great span, has been actually crushed in, what must it become at a distance of several miles? Estimates have been made* of the effects of compression on the assumption that the inner parts of the earth are composed of materials similar to those of its crust, and it has been ascertained that its density would gradually increase, until at a depth of 2000 miles (about halfway down) it would be thrice that of the surface—in other words, clay would be compressed till it was as heavy as iron, while at the center it would be almost four times its original weight. On the supposition that the law of density, on which these statements are founded, holds good, the weight of the earth can be calculated, and the result obtained is considerably in excess of the actual weight. Hence there must be either something very abnormal in the composition of the interior, or some force in operation to counteract the effects of pressure, and this would be done very effectually by heat. It must not, however, be assumed that the temperature continues to increase, as the center of the earth is approached, at anything like the rate which has been inferred from the observations already mentioned. If so, the heat at a very few hundred miles from the surface would be almost inconceivably great, enough to fuse the most refractory substances known in our laboratories, and further down might even rival that of the sun. Lord Kelvin has investigated the question on the assumption that the globe is a cooling mass, and has found that after a depth of a few miles the increase of the earth's temperature becomes less and less rapid. If, near the surface, it be 1° F. for every 51 feet of descent (probably rather too liberal an estimate),† this would hold good, roughly, down to about 20 miles; but at a depth of about 80 miles the increase would be reduced to 1° F. in 141 feet, and at about double that distance from the surface it would not be more than 1° F. in 2250 feet, after which it would go on in a rapidly diminishing ratio. Still, in any case, at a comparatively moderate depth—for instance, from about 25 to 30

* By the eminent mathematician Laplace, author of the "Traité de Mécanique Céleste," who died in 1827.

† This was in accordance with the older observations, in which certain precautions were not observed. The more accurate methods adopted of late years have tended to reduce the rate to that stated above.

miles—a temperature would exist which would suffice at the surface to fuse most rock, for at the latter depth the calculated result would be 3147° F. Of course there would be a considerably increased pressure, which would raise the fusing point of the rock, but the density would not be so greatly altered as to produce a very marked difference; for even at 250 miles it has only risen to 3.1 if the average on the surface be taken at 2.5. It is therefore possible that the material of the earth may not remain solid for more than a very moderate distance from the surface. Pressure and temperature are acting in antagonism, and the latter may prevail over the former. This suggests the inquiry, What is the condition of the earth's interior—is it liquid, or does it, after a zone which is melted by the increasing temperature, again become solid through pressure, or is it solid throughout?

This fascinating, but extremely difficult, problem belongs to the province of mathematical physics, and so lies outside that of the geologist, though his special researches may enable him to contribute toward its solution certain facts which cannot be left out of consideration. It has, however, engaged the attention of several eminent men of science, and they are by no means in accord in their conclusions; for though the method adopted may be unimpeachable, sundry data are necessary in the investigation which are at present by no means determined with certainty. As Professor Huxley once remarked, in so many words,* the value of the grist from the mathematical mill depends upon the quality of the corn which is put into the hopper; hence while some, like Lord Kelvin, have come to the conclusion that the earth is solid throughout, others, like Hennessy, have maintained that the crust may not be more than some twenty miles thick, and that all within it is fluid; others adopt a *tertium quid*, and are of opinion that, after an interval of fluidity, the mass again passes back into a solid condition.

Though mathematicians are not unanimous, the majority seem inclined to regard the earth as practically solid, while the idea of a rather thin crust finds, perhaps, more favor among geologists. With the former two arguments for a long time evidently carried great weight. The one is founded on the so-called precessional movement of the earth's axis, which does not remain parallel to itself at every point of the orbit. What happens may be most readily understood from a model of a solar system, such as one of

* Presidential Address to the Geological Society, vol. xxv. 1869, p. i.

the old-fashioned orrerys. Suppose the axis about which the earth turns to be represented by a straight wire, like a knitting needle, thrust through the model globe, and that another wire, at any moment, is run parallel to it through the sun. If the two are constrained to keep always parallel, one to another, the latter, by its movement, will conveniently indicate the changes of position in the former. If the earth's axis remained parallel to itself in every part of its orbit, this line would be unmoved. But, on the contrary, it moves slowly onward: it sweeps out in space a conical surface, and completes an entire revolution once in 25,898 years. The precessional movement thus represented is produced by the attraction of the sun and moon on the protuberant matter in the equatorial region of the earth. If this latter were a true sphere, no such movement would exist; sun and moon, as it were, pluck at the earth's girdle while it goes spinning round, and the "jerk" makes it stagger. When a top is "asleep" a similar movement can be produced by tapping it gently with a knitting needle. The amount of precession can be calculated theoretically; it depends upon the mass of the inner sphere, which the outer girdle must, so to say, carry along with itself. If the earth consisted of a fluid incased in a solid shell, and the latter could turn upon the former with little or no friction, then the precession would be much greater than it is at present, because the inner mass would be comparatively ineffective as a "drag" against the disturbing influence of the outer ring. It was maintained by the late Mr. Hopkins that the observed amount of precession indicated that the earth's crust must be at least from 800 to 1000 miles thick, and the globe, as a whole, not less rigid than glass, and this view was supported by Lord Kelvin; but recent investigations have tended to weaken the arguments in favor of the earth's solidity, so far as they rest on precession, for Professor G. Darwin has shown that, in certain cases, the precessional movement in a fluid spheroid is the same as that in a rigid one.

The other argument is founded on the tides. The combined attraction of the sun and moon, as already described, produces a wave which travels round the globe. The water, so to say, is lifted up from the crust into a heap, and thus rises and falls against the land, which is fixed in position. But if the crust were flexible, it would yield to the attraction like the water; it too would have its own tidal wave, and that in the ocean would be no longer perceptible, since the land would rise and fall with the water.

In order that tides should be as they are at present, the globe must be not less rigid than steel; so that, if not wholly solid, it must at least have a crust more than a thousand miles in thickness.

The arguments—if the question be regarded from the geologist's point of view—on the whole, seem favorable to the existence, at any rate, of a fluid zone at no very great depth. It is admitted that, at a distance of from twenty-five to thirty miles a temperature should be reached which probably would be sufficient to fuse most, if not all, rocks and very many metals, even under the increased pressure. He observes in mountain chains the evidence of intense lateral thrusting, which seems most naturally and simply explained by contraction of the crust. The amount, however, of this is considerable; the formation of an important chain frequently implies the diminution of the earth's surface by an area at least three or four hundred miles in length, and from sixty to a hundred in width. When it is remembered that mountain chains have been developed, probably from the most remote period, at various times in the earth's history, doubts arise whether these do not indicate a reduction in volume more than can be explained on the hypothesis that the earth both is and has been a solid body losing heat by radiation. This certainly is a difficulty, but it may not be insuperable. A very small diminution in the earth's radius, supposing the effect to be concentrated on a single zone of its crust, would give birth to a considerable mountain chain. As against this it may be fairly urged that we have no right to assume that the effect of a general contraction will be concentrated on a single locality, and that even on this hypothesis the amount required would be too large.

A few years since Mr. C. Davison called attention to the distribution of strain in the outer part of a solid globe which was losing heat by radiation.* He showed that the exterior portion of the crust would be in a state of compression, but that this would gradually diminish in amount, until, at a very moderate depth, it vanished. Below this level the direction of the force would be reversed, and the rocks be in a condition of extension. On the assumption that the globe was cooling under conditions perfectly uniform, this "zone of zero strain," as it is termed by Mr. Davison, would lie at a depth of only about five or six miles. If this be so, then the process of

* *Geol. Magazine*, 1889, p. 220.

mountain making must be concentrated into a very limited thickness of the crust, and be very superficial in character as compared with the globe as a whole. That, at any rate, even the mightiest mountain chain is but a trifling rugosity compared with the vast mass of the earth has been already indicated in a former chapter.*

So we must confess that, when we review the whole question of the condition of the earth's interior, it seems impossible, at present, to come to any definite conclusion. Many geological phenomena, as Mr. O. Fisher has maintained, † would be more easily explained on the hypothesis that a fluid interior underlies a comparatively thin crust; but the conclusions of mathematicians, though they rest, it must be admitted, on data which are not beyond question, are generally favorable to the solidity of the globe as a whole. This, however, seems to be certain, that at a moderate depth beneath the surface—thirty miles at most, and perhaps less—a zone must exist at which the rocks, if not actually melted, must be very nearly at their melting point, so that they might pass, in consequence of a very slight change in their condition, from solid to liquid, or the reverse. It must be also remembered that the melting point of a rock is very sensibly affected by the presence of water. The investigations of Guthrie, Lagorio, and others ‡ prove that water, in many cases, greatly lowers the melting point of both minerals and rocks. Hence its access may cause a mass of rock, which is already at a high temperature, to change from a solid to a liquid condition, and by the escape of water the opposite result may be brought about. By capillary attraction water may pass downward to considerable depths in the direction of a heated mass, even where access cannot be obtained through fissures or any kind of divisional planes; and besides this, there is no reason to suppose that its vapor, or at any rate its constituent gases, oxygen and hydrogen, were restricted, when the mass first condensed, to its outer layers; they may have been entangled more or less completely in the inner portions, so that they may be still diffused in the materials of the globe, at least to a very considerable depth.

* P. 12–15.

† In a volume entitled "The Physics of the Earth's Crust."

‡ Of these a good summary is given in Mr. J. J. H. Teall's British "Petography," ch. xiii.

CHAPTER II.

THE ERAS AND SUBDIVISIONS IN GEOLOGICAL HISTORY.

WHEN an attempt was first made to apply scientific principles to the elucidation of the earth's history, the task of the geologist closely resembled that of the archæologist as he disinters the site of a city in the land of an almost unknown people. Before the ground is broken he sees nothing more than some shapeless mounds or confused piles of ruins; where once a stately palace may have risen, grass now grows green; where once the altar smoked with sacrifices, the bird has made its nest and rears its young; where the streets once resounded with the steps of a thronging multitude, only the jackal's howl wakes the silent echoes. But as the work of the spade proceeds, as the trenches are lengthened and deepened, coins, ornaments, weapons, inscriptions, and sculptures are unearthed; the remnants of walls and the ground plans of buildings are laid bare. Beneath the floor of one structure the foundations of another may be discovered. Beneath a layer characterized by one group of articles another may be disclosed containing objects of a different type. That the relics which are discovered near to the surface are newer than those found only at a considerable depth is an obvious inference; it is certain that fragments of carved work built into the walls of one building must have been appropriated from another of earlier date. From such investigations the groundwork of a chronological order is established; by a study of the inscriptions on coins and of the works of art in general some progress is made in filling up its details. But to render the history anything like complete operations of a similar kind must be undertaken in several places. The coins, weapons, ornaments, and utensils of whatever material, the graven patterns, the sculpture and architectural details, must be subjected to a minute and comparative study. Then the wealth of one locality supplements the poverty of another; the light which shines from the one dispels the fog which hung over the over. The evidence which is tendered by all in common, like a "bonding course" in masonry, strengthens the fabric of scientific inference,

and enables the archæologist and historian, as the area of observation is widened, to piece together in an orderly succession the information which once appeared so fragmental and confused. The tablets graven on the crags which overlook the sea near the valley of the Nahr-el-Kelb connect the histories of Egypt and Assyria with that of Palestine, while the study of monuments and cylinders, chiefly during the last half century, has revealed many a lost chapter in the history of nations, has changed the "children of Heth" from a scattered tribe to a powerful people, and not only has revived the forgotten names of the races of Shumir and Accad, but also has brought their bodily forms to light.

On lines such as those which the archæologist is following the geologist has worked. In each district a chronological succession is inferred from the order in which the strata are superimposed. Due allowance has to be made for disturbances such as are produced by the intrusion of igneous rocks, by faults, and the like; localities suitable for study have to be selected, regions where appearances may be deceptive must be for a time carefully avoided, until, at each place, the order of succession in the various strata is established, and the organic remains characteristic of each are determined. Then, after enlarging the area of study, one district may be co-ordinated with another, and the history by this means both extended in scope and rendered more complete in detail. It is here as in archæology; at this or that place gaps may exist in the record; epochs may have passed of which no memorial has been preserved. Cities for a time may have been desolate, and their history a blank, as was that of Jerusalem when its people had been led captive to Babylon, or of Aquæ Solis while Britain was becoming England. At one site the story may be cut short at an early date, as it is at the mounds of Hissarlik or of Nineveh; at another it may be continuous, though with occasional interruptions, from very ancient times. So is it with geology. In this place the record may have been speedily closed; in that it may have begun anew, after a long interruption; in a third it may be continuous. But in the first and second cases the gaps which exist in one district may be filled up from another by means of the study of fossils, and the history of the earth as a whole be rendered fairly complete.

Fossils, then, to use a happy phrase, are the "medals of creation." They are to the stratigrapher what coins and inscriptions are to the archæologist and the historian—the means of restoring order to confusion and of making chronology possible. They are, however,

more than this; for they have also a tale to tell as to the history of life and its development. Strange as the forms may be which science builds up when it bids the dry bones live, almost grotesque as the creatures of a dream, these fall into their place in that great

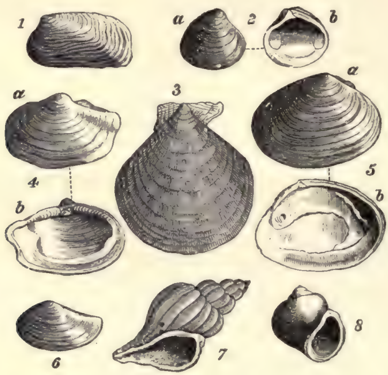


FIG. 120.—SOME OF THE LATEST FOSSILS. (FROM THE SCOTTISH GLACIAL CLAYS.)

1. *Saxicava rugosa*. 2. *Astarte borealis* (*a*, exterior of valve; *b*, interior of valve). 3. *Pecten islandicus*. 4. *Leda truncata* (*a*, exterior of left valve; *b*, interior of left valve). 5. *Tellina calcarea* (*a*, exterior of left valve; *b*, interior of left valve). 6. *Leda lanceolata*. 7. *Trophon clathratum*. 8. *Natica clausa*.

procession which unites the embryonic forms of long past æons with the perfected types of the present age.

But it may be asked, What is a fossil? Though the term is in such familiar use, it is not a very easy one to define with precision. It means, of course, something dug up, with the limitation, however, that this must have been once alive, or a part of a living thing. It would not now be applied to a crystal or a concretion, not even to one of those very ancient tools rudely chipped from a flint, though this might be called a relic of fossil man.* The term also implies a considerable antiquity. The shell of an oyster dug up from the refuse heap of a Roman villa, the antler of a stag from the site of a pile dwelling on a Swiss lake, the skeleton of a man exhumed from a tumulus of an age even earlier than written history, would not be called a fossil, though the term might be applied to a bone of one of his more savage predecessors who hunted the

* Marks such as footprints, worm castings, or burrows, and the like are often preserved, and are commonly reckoned with fossils.

mammoth in days before England had become an island. The appearance of man brings us very near the time limit which custom has imposed on the term.

Fossils are preserved in more than one way. Sometimes, as in certain gravels and clays, they differ from a shell or bone which quite recently has formed part of a living organism only in having lost more or less animal matter, and being thus rendered more brittle and friable. In certain clays, such as that at Bracklesham, mentioned at the beginning of this book, the shells often are so "rotten" that they would speedily crumble away if they were not hardened by being first thoroughly soaked in gum or in a preparation of isinglass, and then allowed to dry. Sometimes, as in the case of peat and lignite, certain further chemical changes have occurred, and an approach is made to the second and commoner method of preservation, when they are mineralized. This process may be effected either by an addition of that chemical constituent of which already the organism chiefly consists, or by the substitution for it of some other substance. Thus the shell of a mollusk from the Chalk is sometimes so completely converted into carbonate of lime that it may exhibit, on a fractured surface, the mineral cleavage of calcite, yet a similar shell in some other formation may be entirely converted into phosphate of lime or chalcedony.* In the latter case the original constituents of the shell have been partially or wholly removed, molecule by molecule, and replaced by a different substance, till a model has been produced which sometimes is so exact as to retain even the most delicate structures. Other minerals besides these two do the same work, such as marcasite, pyrite, chalybite, gypsum, glauconite, and several more, which, however, are even less frequent than the two last named.†

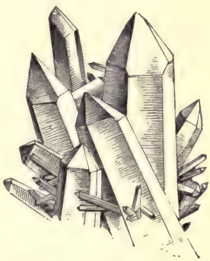


FIG. 121.—A GROUP OF CRYSTALS (QUARTZ).

But when a particular stratum or group of strata has been placed in its right chronological sequence, and can be identified by its

* Calcite is a crystallized form of carbonate of lime; chalcedony is minutely crystalline quartz.

† Marcasite and pyrite are forms of iron sulphide; chalybite is carbonate of iron; gypsum is hydrous sulphate of lime; glauconite consists of silica, alumina, iron, potash, water, and small amounts of other substances.

characteristic fossils, when it can be recognized by this means in districts far apart, which perhaps are severed by physical barriers, such as mountains or seas, a name becomes a necessity, if only for ready designation. Had it been possible at the outset to adopt some principles of nomenclature obvious advantages would have followed, because names would have been excluded which were

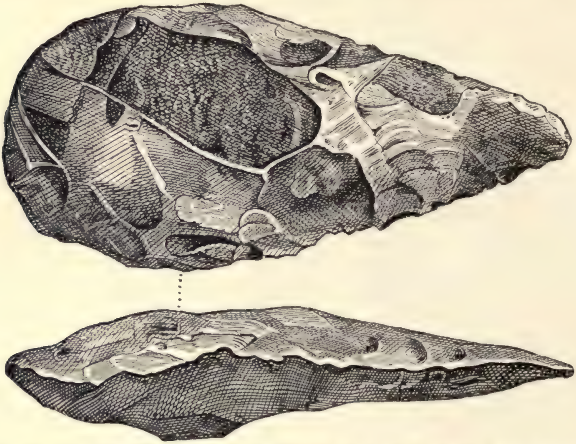


FIG. 122.—PALÆOLITHIC FLINT IMPLEMENTS, FROM ST. ACHEUL, NEAR AMIENS.

misleading, barbarous, or absurd. But geology, like the famous *Topsy*, has "growed"; it has been always the least orderly and systematic of the natural sciences. The man or the junta has not yet arisen sufficiently powerful to sweep away the relics of barbarism and introduce a "Code Napoléon." Thus geological nomenclature follows no definite principle, and in it, as in this world, good and bad are mingled together. Sometimes a group of stratified rocks is named from some lithological peculiarity—as the Greensand or the Oolite, the Cretaceous (chalky) or the Carboniferous (coal-bearing) system. A name thus selected is thoroughly objectionable, because it is only locally appropriate. Chalk, for instance, is only found in certain parts of Europe; in others sandstones or clays were being simultaneously formed. This is occasionally made even worse by adopting some rustic or provincial term for the rock, such as Lias or Cornbrash, Gault or Crag. Some names indicate a local characteristic in a broader sense, such as Dyas or Trias, so

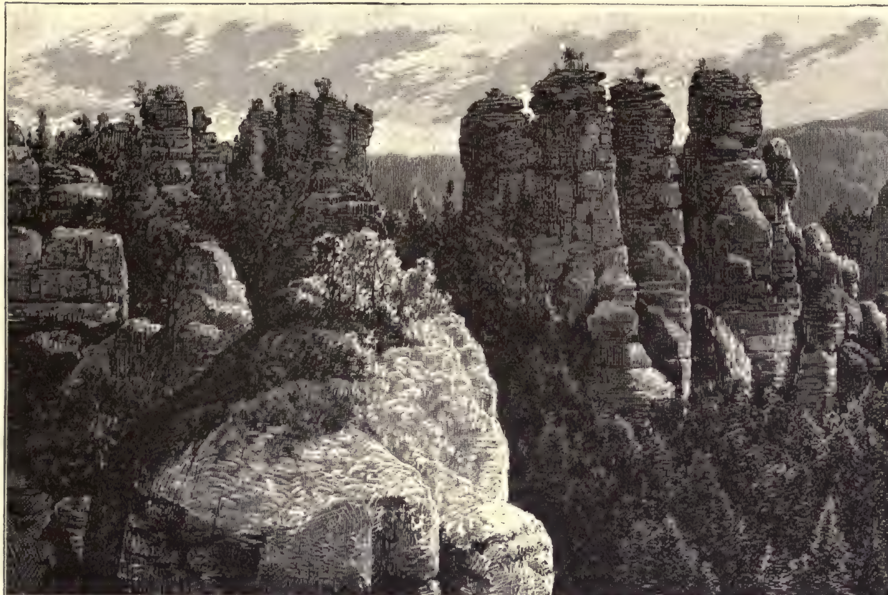


FIG. 123.—ROCKS (QUADERSANDSTEIN): MARTERSTELLE, FROM THE BASTEIBRÜCK IN SAXON SWITZERLAND, CONTEMPORANEOUS WITH THE CHALK OF ENGLAND.

called because either two or three well-marked divisions can be observed in the one connected series. Other names imply a chronological position, such as Eocene or Miocene; but this method is apt to lead into difficulties, for the number of comparative terms is necessarily limited. A name founded upon that of some district or place which exhibits a very fine and typical section of the particular set of strata is least open to criticism—such as Cambrian or Silurian or Jurassic or Portlandian or Kimeridgian—because this name merely states an important fact, and does not suggest any misleading idea; and it can be dropped, if any more characteristic locality be found, no less easily than another. Doubtless the matter is not one of the highest moment. Facts are more important than words, and a "rose by any other name will smell as sweet." Still an unsystematic nomenclature is apt to give rise to slovenly thinking; and geology, as experience has shown, is not a science which can afford to dispense with any safeguard favorable to precision in reasoning.

Whenever a bed of rock is sufficiently characterized by its fossils, or in the absence of these by its mineral contents, a name becomes desirable for purposes of reference, as a counter in the verbal currency expressive of a group of ideas. The smallest mass which can be thus conveniently distinguished from others becomes the geological unit. For such a one the name of a *Stage* has been proposed. A number of these masses which exhibit many common characteristics, but are fairly distinguishable from the stages immediately above and below, may be called a *Group;* * a number of groups similarly connected and distinguished, forms a *System;* and an assemblage of systems forms a *Series*. It has been proposed to use *Era* as a chronological term corresponding with *Series*, *Period* with *System*, *Epoch* with *Group*, and *Age* with *Stage*.

* The terminology here employed differs somewhat from that proposed by the members of the International Geological Congress of Bologna (1881). They adopted the following order, the most comprehensive being placed first: Group, System, Series, Stage. But, as remarked by Sir A. Geikie ("Text-book of Geology," p. 630, ed. 2), "it may be doubted whether the recommendations of any congress, international or otherwise, will be powerful enough to alter the established usages of a language. The term Group has been so universally employed in English literature for a division subordinate in value to Series and System that the attempt to alter its significance would introduce far more confusion than can possibly arise from its retention in the accustomed sense." To this it may be added that the International Geological Congress is not in any proper sense a representative body, and in science the principle of "One man, one vote," does not meet with such favor as it does in some political circles.

Putting aside for the present the minor divisions into groups and stages, we may restrict ourselves to an enumeration of the systems and series which are at present in general use among the geologists of Great Britain and in many other parts of the world, so far as local circumstances permit. For convenience of inspection they are printed in a tabular form, arranged in a descending order, as they might occur in the earth's crust. The most recent—the beds by which the list is begun—though placed as on the table for the sake of symmetry, are hardly of sufficient magnitude to deserve the name of a series, possibly not even of a system. They form the concluding chapter in the earth's history, comparatively brief, but full of interest, in which geology joins hands with archæology, and beyond which, so far as we at present know, the history of man does not extend. In regard to the lowest and earliest—the Archæan—we have not attempted to separate it into systems. Divisions of various value have been proposed, groups have been defined and named; but in the general absence of any signs of life, and in the exceptional conditions which are indicated by so large a part of the rocks, it seems unwise, as will be pointed out in a later chapter, to attempt, with our present imperfect knowledge, any classification which is not admittedly provisional. The intermediate systems are mainly distinguished by the character of their fossils. They are collected into three great "series," which by the older geologists were called respectively Primary, Secondary, and Tertiary—the first, second, and third volumes of life's history. Afterward the names Palæozoic, Mesozoic, and Cainozoic * were proposed, and are now perhaps more frequently used. Palæozoic is certainly commoner than Primary, for this term was entangled at the outset with certain hypotheses which were proved to be erroneous. So Palæozoic was preferred and Primary avoided; for words may experience the fate of men, and if they get into bad company when young may remain for long under a cloud and be viewed askance by respectable folk. This, then, is the list:

Series.	*System.*
Quaternary or Post-Tertiary	Recent and Prehistoric Pleistocene.
Tertiary or Cainozoic	Pliocene. Miocene. Oligocene. Eocene.

* Meaning Ancient-life (time), Intermediate-life (time), New-life (time).

Series.	*Systems.*
Secondary or Mesozoic	Cretaceous. Neocomian. Jurassic. Triassic.
Primary or Palæozoic	Permian. Carboniferous. Devonian. Silurian. Ordovician. Cambrian.
Archæan or Eozoic	Systems not yet distinguished.

While the general order of the divisions is settled, the precise limits of the systems in a few cases are still matters of dispute. For instance, the arrangement which has been followed above does not correspond in all respects with that which is adopted by other writers. The following are the principal differences: The older authors divided the Tertiary into three systems—Eocene, Miocene, and Pliocene. Oligocene, which is composed of the upper part of the first and the lower half of the second, is a term comparatively modern.* In the Secondary series the Cretaceous and the Neocomian systems are called respectively the Upper and Lower Cretaceous. By some geologists the upper part of the Trias is made a separate system under the name of Rhætic. In favor of this change much may be said ; but, as the system is poorly represented in Britain, we have retained the more familiar arrangement. Others group the Permian with the Trias under the name of New Red Sandstone, or Poikilitic, and remove the former into the Secondary series. The name of Old Red Sandstone is sometimes used instead of Devonian ; as will be seen hereafter, it designates only a local and exceptional deposit of that period. The Ordovician of this list forms part of the Silurian of the Geological Survey, being there called simply Lower Silurian, while the one above it becomes Upper Silurian ; while other geologists include the Ordovician in the Cambrian. It may suffice at present to call attention to the existence of these differences of opinion ; the causes of them will be more conveniently noticed hereafter in connection with the details of geological history.

In all these cases the reason for association is the possession of

* The writer is not quite satisfied as to the necessity of the distinction, but adopts it in deference to the authority of geologists who have made the Tertiary deposits a special study.

common characteristics, that for separation the existence of distinctions between one assemblage and another. A comparatively slight change in the fossils, or even a marked change in lithological character, is held to be sufficient in parting stage from stage,* but these must become more conspicuous in the case of groups, and so on. Such interruptions when well marked are called breaks; stratigraphical breaks when there is found to be either a very marked alteration in the mineral character of a large group of rocks or, better still, an unconformity; † or palæontological when one fauna disappears and another takes its place.

It must, however, be remembered that these breaks, after all,

FIG. 124.—UNCONFORMITY: UPPER OLD RED SANDSTONE RESTING ON SILURIAN (VERTICAL), NEAR SICCAR POINT, BERWICKSHIRE.

have only a local significance and value; an unconformity indicates that, after deposition had continued for a certain time, erosion took its place, to give way again to the former process; but, obviously, while rock was being destroyed by stream or wave in one place it was being deposited in another. Neither destruction nor deposition can have ever been universal.

Again, a change in a fauna indicates, not a general destruction of life on the globe, or even over a large area of it, but simply the

* The term *zone* is often used to indicate an horizon in a stage at which a particular fossil or an exceptional group of fossils is unusually prevalent. These zones are often found to be persistent over very considerable areas, and so become of much value in correlation.

† When the base of one formation rests on different parts (sometimes on the upturned edges) of the beds of another below it, this is called *unconformity* or *unconformability*. When the higher beds of a conformable series gradually extend beyond the lower so as to indicate an enlarging area of deposit, they are said to *overlap*.

incoming of conditions in a particular district which caused one fauna either to migrate or to dwindle rather rapidly, and to be replaced by another better suited to the altered circumstances. In some cases also the time of change may have corresponded with one when sediment was being deposited slowly, so that the interval may have been really a long one. Thus two groups or systems, separated in one place by a sharply defined break, stratigraphical and palæontological, may be connected in another by a considerable thickness of deposits, in which the replacement of one fauna by another is much more gradual. For instance, in England the Eocene system is separated from the Cretaceous by a fairly well-marked stratigraphical and a very strong palæontological break; but the gap in some parts of Europe is partially, in others it is completely, filled up, and the Secondary passes into the Tertiary, as mediæval into modern art. Obviously, then, it may be occasionally very difficult to decide where the line should be drawn, not only between the minor, but also between the major groupings. In such case some regard is paid to general symmetry, so that the systems, at any rate, shall maintain, as far as may be, a general equality in chronological value, and not be representatives of periods conspicuously disproportionate in length. A geological classification attempts a task similar to that of arranging for binding the numbers of a periodical which were once continuous, but are now seriously tattered and damaged. The great thing is to get the fragmentary records into a correct chronological sequence, and then to do the best possible in order to make the volumes approximately of the same thickness. At any rate, a bulky tome like Liddell and Scott's "Lexicon" should not stand side by side with one as thin as a quarto copy of the Apocrypha.

As has been already said, all the stratified rocks must have been accumulated within a certain limited time, but we are ignorant as to the length of this. We are not in a very much better position if we seek to obtain an idea of the comparative duration of the Eras or Periods. The only scale on which a computation could be founded would be that of the thicknesses of the several rock masses. On the assumption that the measurements were accurate and a fair average could be obtained by making allowance for coarseness, fineness, and the like, and that the accumulation of each kind of rock had been uniform throughout geological history, it would follow that the times which were occupied in the formation of these several rock masses would be in the proportion of their several thicknesses. This,

though it is a very rough method of obtaining an approximation, is the only possible one; for we are so ignorant of the rate at which a race of living creatures may be altered by the stimulus of external changes that the results of palæontology cannot be profitably utilized at present for purposes of chronological comparison. Still, inaccurate as any results must be, it may be worth while to consider for a moment one of the latest estimates which have been made; for by this method alone can any idea be obtained of the relative durations of the several epochs and eras.

The estimate given by Professor Heilprin omits the Quaternary or post-Tertiary rocks as inconsiderable, for probably their total thickness would fall well below 500 feet. The measurements, especially in the more modern rocks, represent the systems as they occur in America rather than in Europe, where the Tertiary deposits, at any rate, are apt to be attenuated or fragmentary. A new system, the Laramie, is inserted between the Eocene and the Cretaceous, where in Britain and Western Europe generally a break exists of considerable magnitude.

Systems.	*Thickness in feet.*	*Systems.*	*Thickness in feet.*
Pliocene	3,000	Triassic	5,000
Miocene	4,000	Permian	5,000
Oligocene	8,000	Carboniferous	26,000
Eocene	10,000	Devonian	18,000
Laramie	4,000	Silurian / Ordovician	33,000
Cretaceous / Neocomian	12,000	Cambrian	21,000
Jurassic	6,000	Archæan	30,000

This estimate, if the Laramie, for purposes of comparison, be divided equally between the Secondary and the Tertiary, gives for the former 25,000 feet, for the latter 27,000 feet, with 106,000 feet for the Primary or Palæozoic, and 30,000 for the Archæan. Reducing these to percentages, we have Archæan 16, Primary 56, Secondary 13.4, and Tertiary 14.6. Little confidence can be felt, for reasons which will be given hereafter, in the estimated thickness of the Archæan, but the remainder are probably free from any very serious error; so the above table indicates that the Primary strata are just double the Secondary and Tertiary put together, and are, roughly, four times each of them. Supposing, then, that these strata were accumulated at an approximately uniform rate (and there is nothing to prove that this was quicker in Primary times), the dura-

tion of the eras over which these three great divisions of the earth's life history extended would correspond approximately with the numbers 560, 134, and 146.

By means of the comparison of fossils from widely separated localities, and a study of the succession of the various forms of life in the different parts of the globe, formation has been connected with formation and place with place. Thus it has been discovered that the earth was not occupied in past times, any more than now, by the same fauna in all its parts, but that even then representative species and genera existed, together with other differences indicating the effects of geographical limits and climatal conditions. Still, notwithstanding this, the fauna or flora of a particular system is so far marked out by common characteristics that an experienced palæontologist, on comparing a parcel of fossils from South Africa or Australia with those found in a certain system in Europe, cannot fail to be struck by the resemblance between the two. He also finds, on further inquiry, that the correspondences are exhibited by the contents of groups of strata which follow the same order of succession as they do in his own country. Suppose, for instance, one bed reminds him of the Silurian, another of the Devonian, and a third of the Carboniferous of Europe, these beds will come in the same sequence in the opposite hemisphere of the globe. Accordingly, these terms are in use even at the antipodes of the places where they originated, and the epochs which they represent have been supposed to correspond, roughly speaking, in time.

But this notion of geological contemporaneity from the general similarity of fossils must not be pressed too far.* Professor Huxley, who has dealt with this subject in his usual masterly style, has pointed out that the results of the study of fossils might be formulated in two laws "of inestimable importance; the first, that one and the same area of the earth's surface has been successively occupied by very different kinds of living beings; the second, that the order of succession established in one locality holds good approximately in all. The first of these laws," he says, "is universal and irreversible; the second is an induction from a vast number of observations, though it may possibly, and even probably, have to admit of exceptions. As a consequence of the second law, it follows that a particular relation frequently subsists between a series of strata containing organic remains in different localities. The series

* "Lay Sermons, Addresses, and Reviews, No. X. (Geological Contemporaneity)."

resemble one another, not only in virtue of a general resemblance of the organic remains in the two, but also in virtue of a resemblance in the order and character of the serial succession in each." Thus a correspondence in succession, as he says, " came to be looked upon as a correspondence in age or contemporaneity." But it is relative rather than absolute contemporaneity.

At the present time we find that the range of a species, and to some extent even that of a genus, is limited by geographical barriers and climatal conditions. The further spread of this organism is prohibited by ocean depths, of that by mountain barriers or by desert plains ; in one direction the invaders are repelled by heat, in another by cold. " Thus far shalt thou go, and no farther," is a command common enough in the realm of Nature.

Accordingly it is doubtful whether similar floras and faunas could have been strictly contemporaneous in regions far apart, and under very different climatal conditions. Whatever may be the history of the actual origin of a species, this at least seems clear—that, if it has a wide geographical range, this must be a consequence of migration. Accordingly it could hardly begin, and probably would not end, its term of existence simultaneously in two places very far separated—as, for instance, on the same circle of longitude, but on opposite sides of the equator. It is still more improbable that a flora or fauna which has been discovered in some district within the tropics should be contemporaneous with a similar one in temperate regions. Any assemblage of organisms indicates a certain environment, and among its factors climate is not the least important ; but it is almost impossible that the corresponding conditions of existence should have been coincident in regions separated by many degrees of latitude. Much more probable is it that the two epochs thus indicated were in a sequence, that either the denizens of the temperate zones were driven by an increased cold toward the equator, or a migration in the opposite direction was produced by an increase of heat. As changes of climate and the consequent displacement of living creatures, so far as we know, are brought about slowly, any real contemporaneity becomes almost impossible in such a case as this. So far, then, as a conclusion is possible in regard to this matter it may be thus expressed : A correspondence of flora and fauna may be indicative of a general contemporaneity in places which differ considerably in longitude, but only slightly in latitude, while it has the contrary significance if the agreement is in longitude, and the separation in latitude is very marked.

But inasmuch as the second of the laws enunciated by Professor Huxley—that of the persistence of the order of succession—holds good generally, if not absolutely, in all parts of the earth: as chapter follows chapter in the same sequence in the records of the rocks, and in the story of the development of life: the names which have been adopted for one region may be conveniently applied to another, provided it be understood that a definite position in a series, rather than a real contemporaneity, is implied by their use. The latter, under certain circumstances, may also exist, though here the unit of measurement must be centuries rather than years, but under others the difference may be large, as we count time. Still, in most cases, the two groups or systems are not likely to be parted by a wide geological interval. They will be related, so to say, as are the men of successive generations rather than of successive eras. For this correspondence of the floras and faunas of two or more separated groups of rocks, Professor Huxley has proposed the term "homotaxis"* in order to express a correspondence of position without predicating a contemporaneity of time. It is the former rather than the latter sense which must be understood in the following chapters when reference is made to the life history of the earth during any geological period or epoch.

But in any attempt to depict, even in the broadest outlines, the past life history of the globe, and to speculate on the development of successive floras and faunas, the inherent imperfection of the geological record must never be forgotten. It is now a quarter of a century since Darwin wrote that well-known chapter in his classic work on the "Origin of Species," and though since that time the labor of numerous indefatigable writers has filled many a gap and supplied many a link for which he had vainly sought, yet even now the lacunæ are very great, and the materials at the disposal of geologists can never be anything but fragmentary.

These inevitable imperfections arise from various causes, which may be summarized under two heads—the one relating to the restrictions which nature has imposed upon our investigations, the other to the inherent defects of the record itself. As regards the former, we are practically precluded from examining more than a very small portion of the earth's surface. It has been already stated that something over seven-tenths of the globe is covered by sea. Here, then, the dredge may bring up samples of the mud or

* It signifies "the same order."

ooze now in process of deposition, but of the underlying strata we can obtain no information. Again, a great portion of the land itself is hardly less inaccessible. Lakes, rivers, snowfields, glaciers, conceal anything beneath them as effectually as the waters of the ocean; large tracts also are so covered up by sands, marshes, and alluvial deposits as to be practically out of reach. Probably not more than one-fifth of the earth's surface by any possibility can ever be examined, and of that at the present time very large tracts are still unexplored. Little or nothing is known of the geology of considerable areas in Australia and the two Americas, and of still larger districts in Central Asia and Africa. But even in those regions where the palæontologist has done his best the opportunities of obtaining materials for purposes of study are very limited. He is restricted to what can be learnt from the outcropping edges of beds, from the natural sections afforded by ravines, or from artificial excavations in quarries, mines, and cuttings. Yet how small a part of any one stratum is thus subjected to examination compared with its volume as a whole! "We are very much in the position of persons called upon to describe the cloth in a warehouse in which they are only allowed to finger the edges of a few bales. We can reason upon what we *do* find, but must be very cautious in forming theories about what we do not find."*

Next in regard to the imperfections inherent in the record itself. The bodies of many animals are destitute of hard parts—such as shell or bone; that of a "jellyfish" or a "sea anemone" will be quickly disintegrated after death, and it is by the rarest chance that any trace, however faint, of such a creature remains. Again, any animals strictly terrestrial in their habits can only be preserved under exceptional conditions. There are in several parts of England moors which never have been touched either by plow or spade. If a pit be dug, it gives an opportunity of examining the soil which has been virgin for myriads of years—since last the land arose from the sea, whenever that may have been. Take such a moor as Cannock Chase, in Staffordshire; it is now overgrown with brake and gorse, heather and heath, whortleberry, crowberry, and other moorland plants. Here and there is a solitary thorn or oak, or a cluster of birch. Insects flutter over the plants, birds flit from bush to bush, the hawk circles overhead, grouse and black-cock are still flushed on the hillside, the rabbit darts among the fern, and the fox skulks through the gorse. In olden time, when men were

* The author, "Geology" (Manuals of Elementary Science).

fewer and collieries unknown, the wild creatures were far more plentiful than now, yet what record can be found of all these countless generations of plants and animals? The soil, as a rule, is a little discolored by traces of decayed vegetable matter, generally past identification, and that is all. The tree that dies on such a moorland drops piecemeal to the ground; there it lies, wetted by the rain and dried by the sun, till at last it turns to touchwood and then to dust. The smaller plant more quickly suffers the same fate; so too the animal which dies and lies unburied upon the surface, till its bleaching bones pass also into dust and are "blown about the desert hills." The moors till late years abounded in game; herds of red deer almost certainly roamed over them centuries before the fallow deer, which still linger, were introduced. They and other creatures, bigger, and now extinct, have, like an "insubstantial pageant, faded," and left "not a rack behind." Terrestrial animals, and to no small extent land plants also, can only be preserved under exceptional circumstances. If they are mired in marshes, engulfed in chasms, drowned in rivers, swept away by floods, then their remains have a chance of being inclosed in some protective covering and handed down to future ages; but the creature that lies down to die upon the moorland is resolved into impalpable gases and formless dust.

But the possibilities of imperfection in the geological record are not even yet exhausted. Many fossil remains, which for a time have been successfully preserved, may be afterward destroyed. Heat, often due to the intrusion of igneous rocks, may cause great chemical changes, and obliterate all traces of fossils. Water, as it percolates through the more porous strata, may attack the mineral salts in shell or bone, and remove them entirely. A mass of sandstone commonly proves a barren hunting ground for the palæontologist, and the reason, no doubt, in many cases is that which has been just given. Again, large masses of rock have been swept away by denudation, and their organic contents have been ground into powder.

So, on a review of the whole subject, we see that the utmost caution is requisite in this department of geological speculation. Making allowance for the fact that at best we can only deal with the hard parts of animals, the palæontologist arrives at his inferences as to the history of the past. But it must never be forgotten that one grain of positive evidence is more valuable than tons of negative evidence; the latter is only useful in suggesting caution, the former supplies the materials for actual advance.

CHAPTER III.

THE ARCHÆAN ERA.

THE Archæan series contains rocks of very different types. The majority are in a crystalline condition, but some are sedimentary deposits, practically unaltered. These represent the two extremes, but intermediate forms occur which link them together; in other words, not only sedimentary rocks can be found in which crystalline minerals are beginning to make their appearance, and thus to obscure the original fragmental structure, but also schists, which, though they are now thoroughly crystalline, indicate, by their composition and mutual relations, that they must have begun their history as sediments. Of the two extreme types the former, or crystalline one, is a group of rocks the origin of which, as will presently be indicated, is a matter of great uncertainty; the latter differs but little from the oldest members of the Primary or Palæozoic series. It must never be forgotten that the division between those and the newest members of the Archæan series has the same significance (but no more) as that which separates the Primary from the Secondary, or the Secondary from the Tertiary. If we slip unconsciously into the habit of assuming that, instead of a gradual change from the one era to the other, there is a great gulf fixed between them, we shall be quickly entangled in difficulties, with the satisfaction of knowing that they are of our own creation. So the break here, as in other cases, is a question of convenience, subject, of course, to the principles generally adopted in classification.* In some parts of this country, and of others, a zone of fossils—very few indeed in number, but distinctive in character—happens to occur immediately above some beds with well-marked lithological features, beneath which only obscure traces of life have been found; and thus the latter form a good base to the Cambrian system, and introduce the Primary or Palæozoic series. This stage is generally separated by an unconformity from the beds below. These sometimes do not appeaı to be very much more ancient than it; indeed, occasionally,

* See p. 328.

when the above-named zone of fossils cannot be found, geologists differ as to the exact spot where the line of separation should be drawn, but in other cases the unconformity is most strongly marked, and the rocks underlying it are in a very different mineral condition, so that it obviously indicates a very long interval of time. In the Archæan, as already stated, only obscure traces of life have been found, still there are indubitable traces, and a study of the fauna of the Cambrian system leads to the conviction that it does not represent the first beginning of life, but that its denizens must have had a long train of predecessors. So, though at present we can hardly venture to use such a phrase as "the Archæan fauna," the next five-and-twenty years may see this rendered definite and augmented, as has been the case with the fauna of the lowest part of the Cambrian* during the past quarter of a century. If so, geologists must either cease to regard the Archæan as an Azoic group of rocks,† or augment the Palæozoic series by enlarging the Cambrian, or by adding a new system. The rocks of the Archæan series present many special characteristics ; that era was the starting point of the earth's history, in regard not only to the development of life, but also to the deposition of rocks. If ever conditions prevailed on this globe which were markedly different from those of the present age, or of later geological history, this must have been during the Archæan era. For these reasons we purpose to treat it separately from the rest, as forming a kind of introductory chapter to the history of the development of the earth's surface and of its inhabitants.

In many parts of Ross-shire—as, for instance, in the neighborhood of Loch Maree—the lowest rocks visible are rather coarsely crystalline schists and gneisses, in some cases differing little from granite or other rocks of igneous origin. Still, as a rule, they are distinguished by a certain tendency to a banded or a foliated structure, and so depart rather distinctly from the normal types of igneous rocks. When the gneisses are traced for considerable distances over the country, they are found to become yet more variable in character, and to be associated—whether by a gradual transition or

* The most important discoveries were made by Dr. H. Hicks, and announced in a paper by himself and the late Professor Harkness in the *Quarterly Journal of the Geological Society*, vol. xxvii. (1876), p. 384.

† The term Azoic (lifeless) has been employed to designate the Archæan. Others have called it Eozoic (dawn of life). Perhaps, on the whole, Archæan (ancient), proposed in 1874 by Professor J. D. Dana, is better, as it expresses a simple fact.

by a rather sudden change is not yet determined—with various quartzose, or micaceous, or calcareous schists, sometimes even with marbles. Thus, whatever may have been the origin of the more granitic members of this assemblage, we can hardly doubt that the last mentioned were formerly sediments, and that their present crystalline condition has been subsequently assumed. These rocks have been variously called Fundamental, Lewisian, and Hebridean gneisses. For many a mile on either side of Loch Maree they are

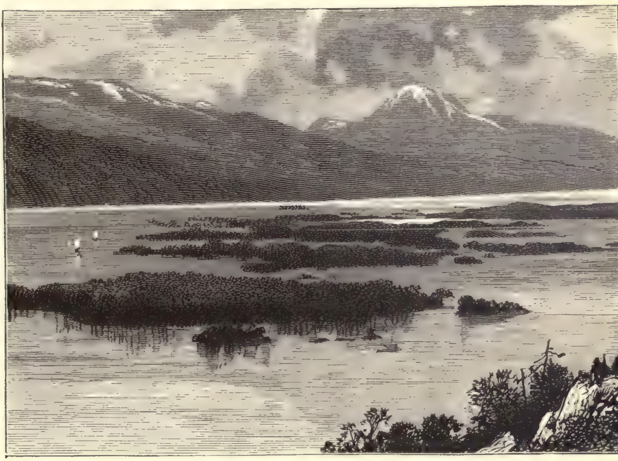


FIG. 125.—LOCH MAREE—AMONG THE "FOUNDATION STONES" OF SCOTLAND.

overlain by a huge mass of ruddy grit, often two or three thousand feet, and sometimes more, in thickness, called the Torridon Sandstone. It is very largely composed of grains of quartz and felspar, and has been so little changed that no doubt can exist as to its nature and origin. These grains obviously have been obtained from rocks identical with those now underlying the grit, the base of which is often a conglomerate or breccia composed of fair-sized fragments of gneiss and schists. The section, then, proves beyond all question that, whatever may have been the history of the Hebridean rocks, they had assumed their present condition, mineral and structural, before the Torridon Sandstone began to be formed. On the latter rock rests a quartzite; between the two another unconformity inter-

venes, which, however, probably does not represent a very long period of time. The quartzite clearly was once a sandstone, and in parts of it tubular markings may be found, which were, no doubt, made by marine worms. The age of this rock can now be fixed with precision. About three years since the geological surveyors* found

FIG. 126.—BEN SLIOCH—A MOUNTAIN OF TORRIDON SANDSTONE.

fossils in some shaly beds just at the top of this quartzite which proved the latter to be at the very base of the Cambrian. Thus even the Torridon Sandstone must be included in the Archæan, and the gneissoid rocks obviously belong to a much earlier part of the series.

In North America an enormous series of crystalline rocks exists, some of which bear a close resemblance to the gneisses and other

* The discovery was described in a paper read by the Director-General of the Geological Survey at the Cardiff meeting of the British Association. *Geological Magazine*, 1891, p. 498.

coarse crystalline schists of the Northwest Highlands.* The rocks cover a vast area, extending northward from the left bank of the St. Lawrence River—from which they were called Laurentian—to the Arctic Ocean, an area probably of about 200,000 square miles. They are overlain in places by a variable system of rocks, which are comparatively unaltered, and sometimes contain fragments of the older series ; to this the late Sir W. Logan gave the name of Huronian. In many places the latter are in turn covered unconformably by strata which are proved by their fossil contents to be of Cambrian age, and the Huronian rocks are now generally supposed, like the Torridon Sandstone, to belong to the latest part of the Archæan series. Rocks similar to the Laurentians crop up in several other parts of North America, though never on so grand a scale, so that in this continent the Archæan series is well represented. Its rocks, as already intimated, exhibit considerable differences in mineral and structural character. Sir W. Logan, who was the first to describe them in any detail, grouped them under two broad divisions, calling the assemblage of highly crystalline rocks Laurentian, and those which were obviously fragmental Huronian. Rocks of igneous origin, for the most part intrusive, are present in both these divisions ; but, putting them aside, the older consist of a very thick mass of gneisses and highly crystalline schists—quartzose, micaceous, and hornblendic—with occasionally some marbles. In the lower part gneissoid rocks predominate, of which the upper exhibit greater variety, and are, on the whole, less coarsely crystalline. The total thickness was supposed to be about 30,000 feet. Sir W. Logan divided this mass for purposes of convenience into two parts—a Lower and an Upper Laurentian. Subsequently it was proposed to sever the latter from the Laurentian and call it the Norian system. The distinction to a great extent was founded on a grave error, for the rock which was regarded as characteristic of this Norian system, and held to be metamorphic, is both igneous and intrusive, so that, as its date is uncertain, it is of no use in a chronological classification. Hence, as no real demarcation has been as yet established, science is not a gainer by the name. One or two other subdivisions have been proposed ; but as their value was never better than doubtful, they need not be included in this volume.

Crystalline schists and gneisses occur in many other parts of the

* There can be no doubt that they are also largely represented in the Central Highlands.

world, which are provisionally referred to the Archæan series. In some cases these can be proved to be earlier than the Cambrian period, in others only to be much more ancient than the oldest rocks which rest upon them. The latter in one place may belong to the Tertiary series, in another to the Secondary, in a third to the Primary. For instance, the crystalline schists and gneisses of the Alps are overlain—here by Jurassic or Triassic strata, there by Carboniferous, there by Silurian. From one end of the chain to the other they have characteristics in common, so that they may be regarded with good reason as an inseparable whole. They present the closest possible resemblance in all essential points to rocks which, in other places, are unquestionably older than the Cambrian period. Hence it seems probable that they too are Archæan. In cases of which this one is a type the age is a matter of inference, for it can only be proved that the rocks are very old; in those previously mentioned it is a certainty. A correspondence in age is inferred from a correspondence in the general characters, more especially in regard to those which are likely to be related to the history of the rock; so that at the present day many geologists (among whom the writer must be counted) would go so far as to say that if a mass of schists be found which appear, in the main, to have been formerly sediment, but are now in a thoroughly crystalline condition, the probability that they are Archæan is so strong that they may be with safety placed, at any rate provisionally, in that series, unless some cause can be shown to the contrary.

The reasons which have led to this conclusion are too technical to be discussed in a work like the present; but an idea of their nature and of the general character of the controversy (which is almost as old as geology) may be indicated in some words written by the author in 1892.* "When the geologist has learnt from the microscope to recognize differences of structure in crystalline rocks and to appreciate their significance, he finds that a wider problem is presented to his mind, provided that he has not been led by the fascinations of laboratory studies to despise or neglect work in the field. Granted that one group of rocks, covered by the term metamorphic, has undergone great changes since its members were first deposited or solidified, can these be connected with any phase in the earth's history? have they any chronological significance? Even

* "The Microscope's Contributions to the Earth's Physical History" (The Rede Lecture to the University of Cambridge, 1892. See *Nature*, xlvi. p. 180).

twenty years since few geologists would have hesitated to reply, 'None whatever: a rock may have undergone metamorphism at any epoch in the past. Muds and sands of Eocene, Jurassic, Carboniferous, Silurian, of any geological age, have been converted into crystalline schists. Proofs of some part of this assertion can be found even within the limits of the British Isles; it can be completely established within those of Europe.' But during the last few years this hypothesis has been on its trial; witness after witness in its favor has been, so to say, brought into court, and has broken down under cross-examination.* I can assert this without hesitation, for I have some personal knowledge of every notable instance in Europe which has been quoted in the debate. Microscopic study, combined with field work, has invariably discovered that some very important link in the supposed chain of proof is wanting, and has demonstrated, without exception, that these crystalline schists are very old, much more ancient always than any neighboring rock to which a date can be assigned. . . It has been also demonstrated that sedimentary masses, after they have been buried deep beneath superimposed strata and exposed to great pressure, have emerged comparatively unchanged. Such rocks are most valuable as illustrations of the effects of dynamical and other agencies; but they are sufficiently distinct from the crystalline schists to indicate that the environment in the one case must have differed greatly from that in the other. The results of contact-metamorphism prove that heat is an important agent of change; but as these also present their own marked differences, they fail to afford a complete solution of the problem.

"Moreover, among ordinary sedimentary rocks we cannot fail to notice that, as a rule, the older the rock the greater the amount of mineral change in its constituents. A good illustration of this is afforded by the Huronian system of North America, the rocks of

* A single instance may suffice to indicate the reckless way in which statements of this kind have been made. At the meeting of the Geological Congress in London in 1888 it was asserted that in some parts of the Alps belemnites occur together with garnets and staurolites in certain nearly crystalline schists, on which ground it was maintained that certain other schists which contain the same minerals are altered rocks of Jurassic age, in which metamorphism has been more extreme. The following are the facts of the case: Some of the rocks in the group, of which the latter schists unquestionably are members, are found as fragments in a rock which all geologists agree in recognizing as Trias (*i. e.*, older than the Jurassic system). The rock which contains the belemnites has not undergone any important amount of alteration, and the minerals in it are neither garnets nor staurolites, but certain hydrous silicates, the occurrence of which has no significance. In a word, a most important generalization is founded on a mistaken identification of minerals.

which are rather older than the Cambrian of this country. Some of them, while still retaining distinct indications of a sedimentary origin, have become partly crystalline, and supply examples of a transition from a normal sediment to a true crystalline schist. Even the older Palæozoic rocks almost invariably exhibit considerable mineral changes, though with them it is only on a microscopic scale. Hence, taking account of all these results, we seem to be forced to the conclusion that the environment necessary for changing an ordinary sediment into a crystalline schist existed generally only in the earliest ages, and but very rarely and locally, if ever, since Palæozoic time began."

These highly crystalline rocks—gneisses and schists of various kinds—with occasional masses of marble, often suggestive of stratification, constitute the earth's foundation stones. In many places we can only pierce through a comparatively small number of layers in its crust, and cannot get below either some members of the Secondary or Primary series, or a rock mass, comparatively little changed, but with nothing to determine its precise age, as it does not contain fossils. Such places supply no information, since the rocks have not been sufficiently crumpled, and the processes of denudation have not cut deep enough into the folds to show what may underlie them. But wherever the base of the sedimentary deposits has been reached, it is found to rest on a crystalline series. What has been the origin of the various rock masses of which the latter is composed is a difficult question, upon which geologists at present are not agreed. Probably some gneisses and schists, particularly the banded varieties of the former, are in reality igneous rocks, which have consolidated under exceptional circumstances, and owe their structure, as already stated, to movements prior to complete cooling. Others, again, may have also been igneous rocks, which, after solidification, were exposed to great pressures, and so far crushed as to assume a rude cleavage, which, in consequence of subsequent mineral changes, was converted into a foliated structure. A third group almost certainly consists of sediments, in which still greater mineral changes have occurred ; for it is difficult to understand how marbles, which pass gradually into a mica-schist, or a quartz-schist, just as a limestone, among ordinary stratified rocks, can be seen to pass into either a shale or a sandstone, can be attributed to any but a sedimentary origin. We cannot, indeed, bring forward a crystalline limestone as a proof that when it was first deposited life existed on the earth (on the ground that ordinary

limestones are largely composed of calcareous organisms), because limestones sometimes are formed by precipitation, as in the case of tufas; but since we do not know of any third mode in which a limestone can be produced at the present time, we are justified in attributing the rock to one of these two origins.

Before we proceed further, the less altered members of the Archæan series should be briefly noticed. These, as already intimated, exhibit a great variety of types. They consist of slates or indurated shales, quartzites, and conglomerates, and occasionally sub-crystalline limestones, together with tuffs, agglomerates, and contemporaneous lavas.* As a rule, a certain amount of mineral change, an incipient metamorphism, is exhibited by all, but the alteration is not great; the newer minerals are comparatively small in size; the original character of the rocks in every case is readily recognized. They differ little, if at all, from some of the lower members of the Palæozoic series, from which probably they are not separated by any enormous interval of time. Of this type the true Huronians † of North America, and similar rocks in other parts of the world, are representatives.

The British districts in which rocks occur belonging either certainly or with very great probability to the Archæan series may be now enumerated. First come the crystalline rocks of the north-western Highlands; these, as already stated, certainly belong to the Archæan era, to the end of which the Torridon Sandstone has been lately assigned. It is no longer needful to express any doubt that a large part of the crystalline masses in the central Highlands are rightly regarded as Archæan, and it is quite possible that some of the fragmental rocks which rest upon or are infolded among these may be ultimately proved, like the Torridon Sandstone, to be earlier than the Cambrian system.

This crystalline *massif* of the Scotch Highlands may be traced through the Inner and Outer Hebrides over to the northwest of Ireland; and the wild mountainous region which extends roughly from Lough Foyle to Galway Bay consists very largely of ancient Archæan rocks. In fact, the more thorough methods of research which have been employed in the investigation of questions of this

* Intrusive igneous rocks are also present, but of these, as they cannot be dated, no account is taken.

† The term has been made to cover some highly crystalline rocks much more closely allied to the Laurentian; but the rocks in Sir W. Logan's typical sections were such as are described above.

kind during the last twenty years have expunged from the maps of Scotland and Ireland the very large areas of "Metamorphosed Lower Silurian" by which they were adorned or disfigured. Archæan rocks also occur in Anglesey and Carnarvonshire. In the former various crystalline schists are common, which, however, have been much affected by subsequent pressure, so that the region offers many difficulties; in the latter the rocks are largely volcanic —lavas (felstones), tuffs, etc. Near St. David's, in South Wales, granitic rocks, some felstones, volcanic tuffs, and diverse sedimentary rocks underlie a conglomerate which forms a convenient base to the Cambrian system in that district. It has been proposed, indeed, to include these rocks in that system, both in Carnarvonshire and Pembrokeshire; but as in each case it has a fairly well-defined base, and there is proof from other districts that an epoch of volcanic activity preceded the Cambrian, which seems to have been generally throughout Britain a period of quiet subsidence and deposition of sediment, this group of rocks, which is one of considerable thickness and importance, appears to be more naturally grouped with the Archæan. At Hartshill, in Warwickshire, at the Lickey Hills, between Birmingham and Bromsgrove, and in the Wrekin and its neighborhood, a volcanic series underlies a quartzite which has now been recognized as "basement Cambrian." Hence the volcanic rocks belong to a late part of the Archæan era. Formerly the hard argillaceous and arenaceous rocks of the Longmynd Hills were regarded as Cambrian, but they have been shown by recent researches to lie beneath the base of that system. At Charnwood Forest, in Leicestershire, slates, with a few bands of quartzite, volcanic agglomerates, tuffs, and lavas, crop up like an island in the Trias. The age of these rocks is uncertain, but unquestionably they are very old and bear a general resemblance to admittedly Archæan rocks in other districts, so that this era is more probable than any other. A rock similar to one of the Charnwood group has been struck, 715 feet from the surface, in a boring at Orton, in Northamptonshire, twenty-five miles away to the southeast, and late Archæan rocks might probably be pierced at comparatively moderate depths in many parts of central England.

The Malvern Hills—"for mountains counted not unduly"—are carved out of a mass of very ancient crystalline rocks which are undoubtedly Archæan,* and similar rocks are exposed, though

* The "Hollybush sandstone," by which they are overlain at the southwestern end, is now identified as basement Cambrian.

rather imperfectly, at the southern end of the Wrekin *massif.* The rugged region about Start Point, Prawle Point, and Bolt Head, in South Devon, consists of schists—chloritic and micaceous—which are clearly disconnected from the Palæozoic slates and cleaved grits to the north, and thus are probably Archæan. The cliffs also all round the Lizard district, in Cornwall, consist of crystalline rocks. The date of these cannot be fixed, but good reason can be shown for regarding as Archæan at least the earlier members of the group, or those which have a bedded aspect. Very similar

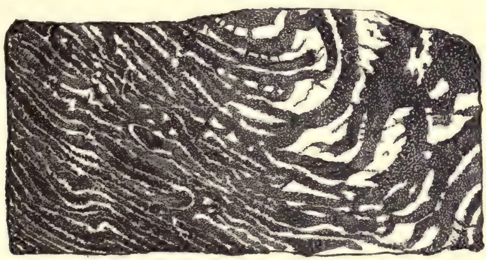


FIG. 127.—POLISHED SLAB OF EOZOON CANADENSE.
(Natural Size.) The dark part is Serpentine; the white Calcite.

rocks occur in Sark, and most of the crystalline rocks in the Channel Islands can be proved to be older than the earliest members of the Cambrian system.

On the continent of Europe Archæan rocks can be identified with more or less certainty in Brittany, Normandy, Auvergne, and in the Alps, from one end of the chain to the other, in parts of Spain, Portugal, Austria, Bohemia, Germany, and of Eastern Hungary and Turkey; they form almost the whole of the Scandinavian peninsula, and the district west of a line joining St. Petersburg with Archangel. The Archæan rocks of North America have been already mentioned, and the era is doubtless represented in the other quarters of the world, but in regard to these our knowledge at present is so imperfect that a bare mention of the fact must suffice.

The traces of life which, as already intimated, have been found in the Archæan rocks next claim a brief notice. The few which are indisputable have been detected only in the latest members of the series, in rocks which till quite recently were generally regarded as Cambrian, and are probably not separated from that system by

any very great interval. From the rocks of the Longmynds come rather ill-preserved markings which have been referred with probability to the shield of a trilobite. At Bray Head, Wicklow, a curious structure has been found, something like the impression of a small branching seaweed.* From Howth come ill-preserved, tiny spherical bodies, which may be radiolaria. At all these places the tracks and burrows of worms may be seen.

When these comparatively unaltered rocks are quitted for the more crystalline and older members of the series, an impenetrable cloud settles down upon the beginning of the history of life. The

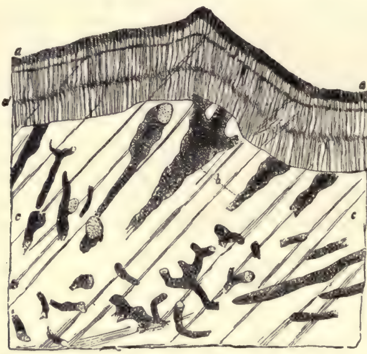


FIG. 128.—STRUCTURE OF EOZOON CANADENSE: FROM A THIN SECTION. Magnified about 100 Diameters (*after Carpenter*).

schists of stratified origin may have contained fossils, but they have undergone such marked mineral changes as to obliterate all traces of organic structures. Some authors, indeed, have referred to the frequent presence of limestone and the occasional occurrence of graphite as proofs that living creatures existed even in these remote ages; but a limestone, as has been already said, may be formed by precipitation—like salt or gypsum—and there is no reason why, under suitable circumstances, graphite may not result from the dissociation of carbonic acid or of carbonates. Hence it

* The genus is named *Oldhamia*, and there are at least two distinct forms. Some consider it to be an alga, some a hydrozoön, some a polyzoön. It is most probably organic, and that is about all which can be said at present. It has been found elsewhere—*e. g.*, in the Ardennes and in Spain.

is unsafe to say more than that the occurrence of these rocks indicates the possibility that life had already begun.

There is, however, one very remarkable structure which many competent judges consider to be an indubitable relic of an organism. Attention was drawn to this about thirty years since, when it was named *Eozoon*, the dawn-animal, with the specific title *Canadense*, from the country where it was first discovered. This is a structure which is so singular, and has provoked so much controversy, that it claims something more than a passing notice; for if its organic nature can be established, life had begun about the middle of the Laurentian rocks, and must be carried very far back in the Archæan era. A specimen of Eozoon consists of two minerals, both exhibiting a certain crystalline structure, the one calcite or dolomite, the other a greenish mineral, either serpentine or some magnesian silicate, generally hydrous. The two are roughly interbanded, and the latter shows a tendency to assume a nodular form, as if it might occupy a series of chambers of oval shape, opening one into another, and arranged in successive layers. (See Fig. 129.) The engraving on p. 345 (Fig. 127) gives a fair idea of the general appearance of a polished section of Eozoon. On examining thin slices of the rock under the microscope the silicate is sometimes seen to be bordered with a zone, or succession of zones, as exhibited in the drawing (Fig. 128) at *a a′*, consisting of calcite, which is pierced by numberless minute "bristles," or threads, of the former mineral. Beyond this the mass of the calcite (*c*) is occasionally traversed by curious branching canals, as they seem (*b*), which are sometimes occupied by the same mineral, sometimes by serpentine or some other mineral. As a rule, these appear and disappear irregularly, and seem to be least frequent where the calcite is most obviously crystalline. The various parts of the Eozoon are connected as in the annexed diagram (Fig. 129), where *A B C* represent the supposed chambers, *b b* the intervening calcite, *a a* the bordering zone, *d* the canal system, and *c* an occasional passage, leading from layer to layer. All this

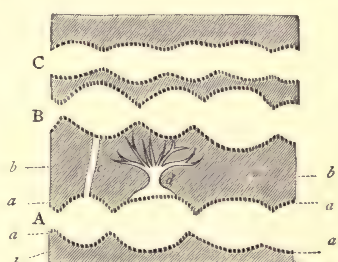


FIG. 129.—DIAGRAMMATIC SECTION OF EOZOON CANADENSE.

is very suggestive of an organic structure, and zoölogists who were familiar with the foraminifera,* a class of organisms belonging to the protozoa, were struck by the resemblance. Commonly the shells of these are very small, but fossil specimens occasionally exceed an inch in diameter. Their plan of growth, also, is usually regular, but a tendency to "run wild" is occasionally exhibited. In the annexed diagram is a section of a well-known type, which, from its resemblance to a coin, is called a *nummulite*. The section (at right angles to the flatter surface) shows the successive layers of chambers, large (c) and small (g), with the dividing walls (h), indicating by the faint striations the minute "foramina" or tubules which characterize this group of animals. In some genera, as at b in this one (though it cannot be shown in a drawing on so small a scale), the "nummuline layers," as they are termed, around the chambers are separated by calcareous material, called the supplemental skeleton, which is traversed by a canal system. Thus one of the higher foraminifera exhibits a group of structures which closely resemble those detected in Eozoon, the main difference being that the latter has a far less regular habit of growth, and attains a much greater size. The advocates of the organic origin of Eozoon urged that the occasional deviations from regularity and resemblances to an inorganic structure which it presented were due to the disturbing effect of mineralization. They also pointed out that, even if it were granted that these structures could find individual parallels among minerals, they were only exhibited in combination by an organism, and that this in itself formed a strong argument for referring Eozoon to the animal kingdom.

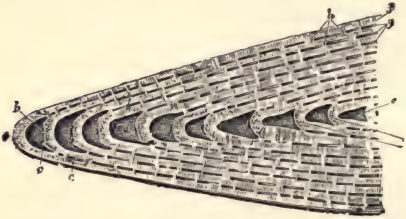


FIG. 130.—VERTICAL SECTION OF A NUMMULITE. (Magnified.)

A question of such difficulty must, however, be looked at from every point of view, so that it now becomes necessary to give a brief description of the appearance which Eozoon presents when it occurs in the field. The account applies to Côte St. Pierre, a little

* See p. 181.

settlement some dozen miles north of the River Ottawa, one of the most noted localities, but probably the others do not present any very marked differences. Omitting some minor particulars, we find there a mass of crystalline limestone, apparently intercalated between two thick groups of gneisses. This limestone in some parts is fairly pure, in others it contains certain silicates. The Eozoon occurs here and there sporadically in masses of irregular form, varying from two or three inches to as many feet in diameter. This is how it most commonly appears: At the center is a lump, variable in shape, of serpentine or of a pale green pyroxene,* or of both,

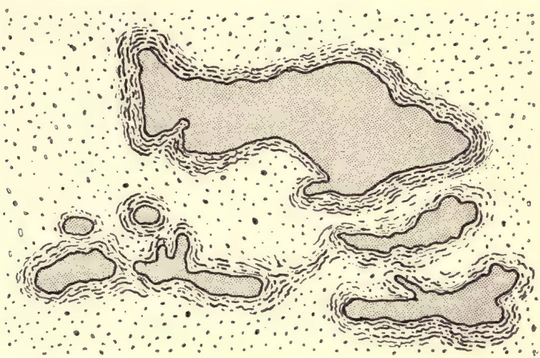


FIG. 131.—DIAGRAM OF ROCK AT CÔTE ST. PIERRE.

Lumps of light-colored pyroxene, sometimes serpentinous; the top one about 2 feet 3 inches long; ringed in most parts with Eozoonal structure up to a thickness of about 4 inches. The remainder of the rock white marble, spotted with granular serpentine.

round which lies the Eozoon for a thickness of two or three inches, and round it comes the crystalline calcareous rock, which is frequently spotted with grains of serpentine or pyroxene about as big as mustard seeds or hemp seeds. If Eozoon is an organism, these grains must also have an organic origin, and be the casts either of smaller foraminifera or of separate chambers of the larger mass. This, however, though not without a precedent, would imply that the process of infiltration was unusually rapid. The presence of the core of serpentine or pyroxene must be accounted for by sup-

* A silicate of magnesia, lime, and iron. The pale varieties (with little iron) pass readily into a kind of serpentine.

posing that the inner part of the organism had perished, and the space been filled up with solid silicate, the true structure being retained only by the outer and more perfect layers. But this does not seem a very probable hypothesis. The rock also has undergone very great molecular changes, in common with the rest of the series, for in no part of it does the slightest trace of a sedimentary origin remain, and this makes it very unlikely that a delicate organic structure should have been preserved.

As a further argument against the organic origin of Eozoon, it is maintained that the chambered structure is less regular than is usual in an animal, as may be seen by a comparison of Fig. 127 with Fig. 130,* and resembles the mineral banding common in many crystalline rocks—the result, probably, of some process of segregation. It is also affirmed that the nummuline layer when decalcified cannot be distinguished from a fibrous structure commonly exhibited by certain serpentines, and the " canal system " is compared with certain minute branching forms assumed by some minerals. We find occasionally, on splitting open a piece of compact rock, that a dark mineral (usually an oxide of manganese) has been deposited between two surfaces where cohesion has been imperfect, and has so curiously imitated vegetable forms that it might be readily mistaken for a fossil plant. Sometimes also in examining thin slices of rock under the microscope we notice an intergrowth of two minerals (generally quartz and felspar) which very closely resembles the canal system. So there is evidently much to be said on both sides of the question. At first the balance of scientific opinion was in favor of regarding Eozoon as a fossil. It was claimed for the animal kingdom by men exceptionally well acquainted with the structures of the lower organisms, and the few advocates of the other view certainly failed in making out a strong case. But their cause of late years has been adopted by much more competent advocates, and it must be admitted that the arguments founded on a microscopic study of the structure seem now to be very nearly balanced, but that the evidence obtained by looking at Eozoon in its association with the Laurentian rock masses is distinctly favorable to the mineral origin.† Still, if this be so, the structure is a very peculiar and exceptional

* It should be mentioned that some of the foraminifera follow a less regular plan of growth than the nummulite.

† The writer feels bound to state that up to 1884 he was a believer in the organic nature of Eozoon, but was beginning to feel the general difficulties presented by the preservation

one, so that the controversy at present can be hardly regarded as closed; certainly much has still to be learned about the genesis of the structure itself, and the history of the peculiar group of marbles to which it belongs.

We have seen that the earlier Archæan rocks are invariably in a crystalline condition, and that, whenever it is possible to arrive at any conclusion in regard to their origin, they prove to be either igneous rocks of an abnormal character—that is, they probably crystallized under conditions now exceptional, but formerly general—or they are sedimentary strata which have undergone very great changes. Metamorphism, as has been already stated, is brought about by one or more of these agents—water, pressure, and heat—but careful work in the field and with the microscope makes it possible to distinguish which of them has been chiefly operative in any particular case. Accordingly we find that the Archæan schists differ in structure from sediments which have been modified mainly by pressure, and approach those which have been affected by a high temperature, though they can be readily distinguished from ordinary cases of contact-metamorphism,* as this is called. The inference thus seems legitimate that these schists were exposed for a considerable time to the action of a rather high temperature. Doubtless water was present, and the rock was subject to a considerable pressure, each of these conditions being no doubt an essential, but not the primary factors in bringing about the result. These schists must have been raised to a temperature above that which a rock attains by being depressed to a depth of ten or fifteen thousand feet below the earth's surface, because there is no difficulty in finding, for purposes of comparative study, Palæozoic rocks—if not any of later date—which have been buried beneath at least that thickness of sediment, and yet have returned to the surface practically unaltered.† These great mineral changes, which have converted a sediment into a rather coarsely crystalline schist, appear to have

of an organism in these rocks. In the summer of that year he had the great pleasure and advantage of visiting Côte St. Pierre with Sir W. Dawson, but he did not return with his wavering faith confirmed.

* Crystalline rocks, sometimes foliated, are produced by this action, but it is convenient to exclude them, as a rule, from the term schist.

† Assuming the conditions to be the same as now, a rock by being buried 12,000 feet below the surface would have its temperature raised by about 200° F.—*i. e.*, the temperature of the mass would be rather above that at which water boils on the surface. This would be favorable to mineral change, but it obviously has been insufficient to produce any effects on an important scale.

taken place at a period comparatively early in the rock's history. The oldest Palæozoic strata only exhibit a slight approach to them; rocks of later date never give more than a "colorable imitation." Though it has been often asserted, it has not yet been proved that a sedimentary rock has been ever converted into a true schist since Archæan times. Enough is now known to justify the assertion that if such a thing can be found, it is very rare and local. These statements, then, which are matters of fact rather than of opinion, suggest that in Archæan times either the earth's crust as a whole was at a higher temperature than it is now, or that, if the surface was nearly at the present temperature, there was then a more rapid increase in descending below it. The rate is now, roughly, 1° F. for 60 feet of descent. On the assumption that the earth was once in an incandescent condition, and has cooled by radiation, Lord Kelvin has shown that though the heat of the interior, after a comparatively short time, would cease to produce any sensible effect upon the surface, the temperature, at the end of one twenty-fifth of the whole time which has elapsed between the first crusting over of the globe and the present age, would rise 1° F. for every 10 feet of descent. The loss of heat from the outer part of the crust at first was comparatively rapid, but it became continually slower. For some while after the epoch just named, foot after foot would be rather rapidly added to the interval corresponding with each rise of a degree in temperature, until, probably, before the world had advanced very far in the Primary era the conditions had approached so near to those now existing that the depression of a mass of rock to a couple of miles below the surface brought it into a zone of temperature only slightly higher than would be found at the present time.

Accordingly since there must have been an epoch, whether any record now remains of it or not, when a temperature equal to the melting point of iron would be reached within four miles from the surface, and everything at a depth of 10,000 feet would be at a dull red heat; since there is no evidence that any such conditions continued even into Palæozoic times, during which, so far as we can tell, the temperature, in the earliest epochs, did not increase at a rate very appreciably more rapid than now: since the evidence, so far as it goes, indicates a quicker increase in the earliest times, and the oldest rocks are always those which have been very greatly affected presumably by a high temperature—we are led, in accordance with the usual principles of induction, to infer that the

Archæan schists are records of the earliest chapters in the earth's history. It is also probable that some of the gneisses and abnormal igneous rocks which are so associated with them as to suggest contemporaneity or priority of formation rather than subsequent intrusion, may be, if not actually part of the primitive crust of the earth, masses extruded at a time when molten rock could be reached everywhere near to the surface, and when the process of cooling, even at a very moderate depth, was much slower than it became in the ages after the earth had begun to be occupied by living creatures.

CHAPTER IV.

THE BUILDING OF THE BRITISH ISLES.

THE geography of the globe at the present epoch is the outcome of its geography in past ages. Each mass of land is the result of two processes—the one of deposition, the other of sculpturing. By the former its materials were collected and built up, by the latter its surface was molded and its boundaries were defined. These chapters in the physical history of each region may be recovered. This is the task of the geologist: to delineate in a series of sketches the changing scenes—as sea was replaced by land, or land by sea; as island groups coalesced into continents, or continents were severed and submerged; as mountain chains arose, and as even they, at last, were brought low. The materials which enter into the composition of a deposit, the changes which the latter exhibits as it is traced across the country, afford clews to the nature, the position, and the grouping of the old land masses, so that the microscope in the hands of workers who are capable of looking from the small to the great is a bridge across vast intervals of time, like the spectroscope or the telescope across the abysses of space. The difficulty of any attempt to reconstruct the physical geography of past ages necessarily increases with the distance of the time, for the evidence must obviously become more and more imperfect and fragmentary. The older a mass of rock is the more unfrequent and limited are likely to be its outcrops; or, in the rare cases where land has remained above the sea for long epochs, the more carious, worn, and ruinous, and so the less suited for examination, will its surface have become. From this it follows that any attempt to reconstruct the physical geography of a district in the earlier part of the Primary era is almost hopeless; to succeed in indicating the position of land and sea is the utmost that can be expected; but as time proceeds, the difficulties gradually diminish. Want of space precludes any attempt to enter into a detailed history of each region on the surface of the earth, and in not a few the task would be hopeless at present for want of sufficient materials; but we will endeavor to give some idea—though even this must be in

bare outline—of the building of the British Isles during the several geological periods, and then indicate, still more imperfectly, the probable story, or rather some fragments of the story, for each continent. These isles, as already intimated (pp. 52 and 57), are in close connection with the northwest part of the continent of Europe (Fig. 19, p. 53); their geology is a sample—we might almost say an epitome—of its geology; their history is really inseparable from its history; so that in the endeavor to decipher the story from our own country we shall be led, almost insensibly, to recover it for a considerable area of the adjoining mainland.

It is a hopeless task to attempt to reconstruct the physical geography of Britain prior to the beginning of the Cambrian period. Even for this time the materials are very fragmentary. Only in the northern part of Scotland and the northwest of Ireland are any large masses of the earlier Archæan rocks still visible. These, at any rate in the former, appear to have undergone great denudation in the epoch immediately preceding the Cambrian; their ruins formed the Torridon Sandstone, and the process of destruction obviously continued during the earlier part of the Cambrian period. In some districts of Britain—as, for instance, in northwest and southwest Wales, in Shropshire, Warwickshire, and probably Leicestershire—the Archæan era was closed by oscillatory movements of the earth's crust and sporadic volcanic activity. These disturbances, as is frequently the case, appear to have been the prelude to a long-continued subsidence of the crust, affecting a considerable portion of Britain, during which the Cambrian strata were deposited.

These, in Britain, are divided into four sub-groups—the Harlech or Lower Cambrian beds, which may have a maximum thickness of some 8000 feet; the Menevian, a comparatively thin but palæontologically well-marked group, measuring only about 700 feet; the Lingula Flags, sometimes as much as 5000 feet; and the Tremadoc Slates, about 1000 feet. In Scotland the scarcity of fossils makes it difficult to know to what extent deposits of Cambrian age are represented, and it has only been ascertained quite recently by the discovery of an *Olenellus** that the white quartzite of the northwest Highlands lies in reality at the base of the Cambrian system. Its materials evidently, like those of the preceding Torridon Sandstone, were derived from the coarse crystalline rocks of the adjacent region; so that the existence of a considerable mass of land formed

* A trilobite, one of the earliest known genera.

of such rocks is indicated, which lay, probably, to the northwest. In like manner the Lower Cambrian or Harlech beds in England generally intimate by their materials the proximity and the destruction of a land composed of crystalline rocks. It is very doubtful whether any part of the Cambrian system can be identified in Ireland. In County Wicklow rocks exist which originally must have been sandstones and muds; these were formerly referred to the Harlech group, but they are now considered to be slightly earlier. The occurrence in Connemara of Ordovician rocks, containing numerous fragments of the Archæan crystalline masses, indicates the gradual subsidence of a land region which probably extended, at any rate in earlier Cambrian times, over a large area both west and east of that country. An overlapping of the Cambrain deposits in the Harlech and the Carnarvonshire areas is exhibited in North Wales, for in Anglesey, according to our present knowledge, Upper Cambrian or Ordovician strata rest on various pre-Cambrian rocks. Hence the sea must have gradually deepened and crept northward over Anglesey, which, for a time, formed part of the coast line. Indications of another coast line may be detected in Cornwall, and picked up again in the Channel Islands, Brittany, and Normandy. Altogether it seems probable that the site of England and Wales, perhaps also of Scotland, in Cambrian times, was a rather shallow sea, the area of which gradually extended as its bed sank, and in which sediment was plentifully deposited, supplied from a large mass of land (in which Ireland may have been included), at no great distance to the northwest, west, and southwest.

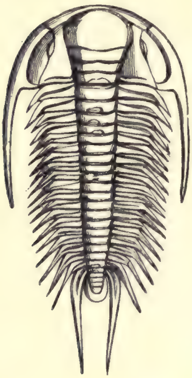


FIG. 132.—A LOWER CAMBRIAN TRILOBITE (*Paradoxides*).

The Ordovician system is subdivided into the following groups: The Arenig, attaining a maximum thickness of 2500 feet; the Llandeilo, amounting to about 3000 feet; the Caradoc or Bala group, very variable in thickness, but sometimes exceeding 4000 feet; and the Lower Llandovery, a comparatively unimportant group, evidently transitional in character, which varies from about 600 to 1200 feet. Ordovician rocks occupy a considerable part of Wales, more especially on the western side; they occur on the eastern

border and in Shropshire ; also in the Lake District, in western Yorkshire, and in the Isle of Man. They are occasionally exposed in the southern uplands of Scotland, as about Girvan and Moffat ; they crop out in the northwest and northeast of Ireland, and have been detected in Cornwall, in the vicinity of Veryan Bay, and in the Meneage district. Probably a large part of Great Britain and Ireland was covered by sea during this period, though the expanse of water may have been interrupted locally by islands. In Arenig times volcanoes were active in North Wales. Relics of these are preserved in the mountainous region which culminates in the Arenigs, the Arans, and Cader Idris, as well as in that of the Berwyn Hills. In Llandeilo times the seat of disturbance seems to have shifted southward to Pembrokeshire, and northward to the lake district, where ashy slates, tuffs, volcanic breccias, and lava streams make up a mass of rock not less than 10,000 feet in thickness, in which not a single fossil has been discovered. It has been recently ascertained that there was also a considerable amount of volcanic action at this epoch in the southern uplands of Scotland. The eruptions of the Lake District ceased early in the Bala epoch, but then volcanoes broke out afresh in North Wales—this time, however, in the Snowdonian district and east of it at least as far as the valley of the Conway. These last, at any rate, must have been submarine, for on the peak of Snowdon an ashy slate full of characteristic Bala fossils is intercalated between lava streams, the lower group of which forms the grand cliffs which overhang Glaslyn. The volcanic disturbances, at the one or the other of these epochs, also affected other areas in the northern half of Wales, as far west as the Lleyn and east as the Corndon district, but in some of them it is more difficult to ascertain the precise date. The geography of Great Britain and Ireland during the Ordovician period may be concisely described as—a sea of variable depth, with a mass of land, still large, on the northwest, west, and southwest. The shallower parts or the islands of this sea from time to time were disturbed by volcanic outbursts, sometimes of great violence. The period was closed by important movements of the earth's crust. Now began, in all probability, the mountain making of the Scotch Highlands, affecting a large district, of which the northwest of Ireland is only a fragment. The northern part, at least, of Wales was similarly disturbed, and by these movements were produced the cleavage of its older deposits, as well as the interruption between them and the base of the rocks which come next in succession.

The Silurian system is divided into three groups: The Upper Llandovery, which may attain a thickness of 1000 feet; the Wenlock, which is often full 1500 feet; and the Ludlow group, which occasionally reaches about 1800 feet. Deposits of Silurian age probably exist in all parts of Wales not previously mentioned, for they form a large part of the surface around the patches of older rock; they crop up, here and there, through a newer deposit (the Old Red Sandstone) in the south, and rise from beneath it on the east. Similar evidence justifies the assertion that they extended into the English Midlands, for an occasional outcrop from beneath newer rocks indicates, like a skerry projecting from the sea, that a mass of rock is hidden beneath the surface. Whether they ever extended as far as Leicestershire, eastern Warwickshire, and Northamptonshire is more doubtful, but they have been struck in a boring beneath Ware, in Hertfordshire, so that the apparent interruption to the continuity of the deposit may have been caused by an island which at that time occupied the site of the Midland counties. Certainly the sea extended northward over Cumberland and Westmoreland into Scotland, the greater part of the southern uplands consisting of Silurian rocks,* but very probably the Highlands had now risen well above water, and the mountain making went on continuously. Silurian rocks have been found in western Ireland—in Galway, Mayo, and Kerry—and in certain localities in the northeast. From the former it is evident that, as in Scotland, great earth movements had preceded the deposit of the basement bed of the Silurian,† while from the relation of the older rocks of Dublin, Wicklow, and Wexford to those which rest upon them (Old Red Sandstone), it seems more probable that this region was above water in Silurian times, perhaps forming part of an island which may have extended to the western margin of North Wales.

The Silurian deposits furnish some interesting facts which have a direct bearing on the physical geography of the period. In Shropshire, Herefordshire, and Monmouth, and to the east, so far as known, they are very dissimilar in composition from their representatives in central and northern Wales, in the north of England, and in southern Scotland. The difference mainly is this: The former, at any rate after the Upper Llandovery, include limestones, one of

* Here, as in the Lake District and in West Central Wales, the break between Ordovician and Silurian is slight or imperceptible.

† Sir A. Geikie has given reasons (*Nature*, xl. p. 323) to prove this, and to make it probable that the disturbances continued in Silurian times.

which, the Wenlock limestone, is fairly thick and extensive, and are generally fine-grained, mudstones predominating; the others have no limestones, but consist of fragmental materials, varying from shales to fairly coarse sandstone. A study of the microscopic structure of the last named proves that masses of coarse crystalline rock and volcanic materials must have been undergoing denudation, thus indicating the continued existence of the northwestern land already mentioned, of which the present Scotch Highlands must have formed a part, and suggesting that of a region of some size and elevation to the west of North Wales. The Silurian period seems to have been, like the Cambrian, one of quiet and slow subsidence, unruffled by volcanic explosions, except in the extreme west of Ireland, near Lough Mask, and in the wild headlands of Kerry about Dingle Bay.

The Devonian system has not been so generally divided into groups, other than is expressed by the use of the terms Upper, Middle, and Lower, as the preceding systems, but it presents us with two distinct types, being the first instance in the country of an anomaly which afterward occurs more than once. The system is represented in one region by strata of a normal character, evidently deposited in the sea; in another by rocks which, whatever may have been their origin, are clearly abnormal. To the former the name Devonian properly belongs; to the latter the descriptive title of Old Red Sandstone was given at an early date, and might still be retained to designate the abnormal type. In this country the relations of the marine beds to deposits of earlier date are not very clear. They only crop out to the south of the Bristol Channel, and underneath them no Silurian strata have as yet been recognized; these are either wanting or represented by unfossiliferous deposits. That the Devonian strata underlie the Carboniferous system is clear, for that occupies a trough, bounded on the north and south by Devonian rocks. The only difficulty consists in settling exactly where the line between them is to be drawn. But the position of the Old Red Sandstone is clearly defined. There is a gradual passage into it from the Silurian system. There is one no less gradual from it into the Carboniferous. As the fossils characteristic of the older deposit disappear, the rocks assume a red color, and become sandy. Their fossils, which usually are not common, are of rather peculiar types. This state of things continues often for some thousands of feet, then the color begins to change, the red sandstones or marls are replaced by yellow or grayish calcareous rocks

or by dark shales, and the fossils characteristic of the Carboniferous system make their appearance.

For a more complete knowledge of the marine deposits of the Devonian period we must turn to other countries. From these we learn that it is not only entitled to the full rank of a system, but also that it is intermediate between the Silurian and the Carboniferous. The boundaries of the sea in which it was deposited can be more easily discussed after the Old Red Sandstone type has been described. The latter is found in insulated patches, which, however, are sometimes very extensive. One covers a large part of southern and southeastern Wales—probably it extended over all the rudely triangular area between the Bristol Channel, a line drawn roughly from St. Bride's Bay to the Wrekin, and one running southward from the latter to somewhere near the eastern end of the Mendip Hills. A second occupies part of Northumberland, and curves round the southeast end of the southern uplands of Scotland. A third patch flanks both the northern side of these hills and the southern side of the Highlands, and probably underlies the whole of the central valley of Scotland, extending into northeast Ireland; a fourth is situated on each side of the Moray Firth, extending even as far as the Orkney Islands, and running up as well into the Great Glen. These all cover considerable areas, but there are also small patches of similar character in Lorn and in Donegal. In the south of Ireland rocks of an Old Red Sandstone type occur and are well developed. These pass up, as usual, into indubitable members of the Carboniferous system, but are found to rest, with marked unconformity, on a thick series of gritty beds, which overlie true Silurian rocks, and resemble in general character some of those in Devon, though as yet they have not yielded any fossils.

The marine or normal Devonian rocks are often fairly rich in organic remains; not so, as a rule, those of Old Red Sandstone type. Neither are the fossils in the latter, when they do occur, very helpful in throwing light upon the history of its origin. They are chiefly plants, fishes, and a peculiar group of crustaceans, which will be more particularly noticed in a later chapter. They are not, indeed, altogether restricted to these deposits, and elsewhere have occurred with fossils indubitably marine, and one or two such fossils actually have been found in the Old Red Sandstone of South Wales; but the evidence on the whole makes it probable that the Old Red Sandstone was not deposited in the sea. By most geologists it is regarded as a lacustrine deposit, and geographical names have been

assigned to the several areas.* Some, however, think that the sea may have occasionally gained access to the lakes which covered South Wales and the central valley of Scotland—if, indeed, the former were not always an estuary. In that case it would have been in direct continuity with the sea which overspread North Devon, the deposits of which now and again bear a resemblance to those on the north side of the Channel. This sea also probably covered—at any rate during the earlier part of the time—the southwest of Ireland.

Be this as it may two facts are certain: One, that during this period Great Britain was the scene of severe volcanic eruptions. South Wales, indeed, appears to have been undisturbed; so also, with some comparatively slight exceptions, were Devonshire and the district of the Moray Firth. Not so, however, the other regions. The Cheviots, the Pentlands, the Sidlaws, the Ochils, and many another northern group of hills, are mainly formed of piles of lava, agglomerate, and tuff, ejected by the Old Red Sandstone volcanoes. These belong almost always to the lower part of the system. Not only this, but the mountainous region also—especially in the central Highlands—is repeatedly riven by dykes of compact igneous rock, and not seldom invaded by huge masses of granite. Almost all the former, and not a few of the latter, probably belong to this era, and indicate that during Old Red Sandstone times a large part of Scotland was studded with active volcanoes, many of which probably were on a scale far grander than Vesuvius.

The other fact is this—that during the Old Red Sandstone period denudation was active, and affected a large tract of land. The sandstones indicate the destruction of huge masses, either of earlier sandstones or of fairly coarse granitoid rocks. The pebble beds which abound in Scotland are crowded with fragments derived not only from the volcanoes just mentioned, but also from the Archæan and earlier Primary rocks of the Highlands. The great northwestern land, remnants of which are left to us in the latter district and in the northwest of Ireland, must by this time have developed into a mountain region, seamed with torrents and rivers, which was being sculptured into peaks and glens and valleys. A period of earth movement, which lasted all through the Silurian, was probably

* In Scotland the southeastern area is called Lake Cheviot; the central one, Lake Caledonia; the northeastern one, Lake Orcadie; and the small western basin, Lake Lorn. Lake Fanad is the name proposed for the one in Donegal, and that in Wales is simply called the Welsh Lake.

ended by an episode of more active disturbance, which produced the southern uplands—perhaps also some of the most remarkable dislocations of the Highlands themselves—which correspondingly quickened the action of the denuding forces, and resulted in the comparatively rapid accumulation of great masses of conglomerate and sandstone. These may have been formed in lakes—certainly their present distribution accords well with that idea—but in any case we need not hesitate to recognize in them the *débris* of a mountain region, and proofs of the marked change which had passed over the eastern margin of that great land area of which indications have been afforded from so early an epoch. They tell us that the Scotch Highlands, in their present form, are only the ruins and the remnants of a mountain chain which has existed from the very beginning of the Devonian period.

The Old Red Sandstone itself indicates that even while it was being deposited disturbances had not ceased. In all the northern regions one well-marked break may be generally recognized, and, as some think, a second also. An unconformity—conspicuous on both sides of the central valley—separates the Upper Old Red Sandstone, which passes on into the Carboniferous, from the Lower Old Red Sandstone, which no less clearly passes down into the Silurian. True, there is little sign of this unconformity in the Moray Firth district or in South Wales, but it is well marked in Ireland, both in the northern and in the southern regions. In the latter the Upper Old Red Sandstone, which may be roughly described as representing the Welsh or Scotch type, is always unconformable with the underlying rocks. It was deposited in a sheet of water which probably covered all the south of Ireland from near Galway Bay to the hills of Wicklow, Wexford, and Carlow, and it rests in places, as said above, on a mass of unfossiliferous grits and slates higher than the Silurian. Thus it seems probable that Scotland and Ireland were the scene in the Devonian period of considerable physical disturbances, which indeed may not have been without some effect even in the southwest of England. All the evidence at our command indicates that ordinary marine conditions cannot have existed north of the Bristol Channel; though possibly South Wales, at any rate for part of the time, may have been covered by an estuary rather than by a lake. But North Wales, the Midland counties, and most of the north of England probably formed part of a considerable tract of land, for here, as we shall find, rocks belonging to various horizons in the Carboniferous system are often found resting upon

deposits which are not newer, at any rate, than the top of the Silurian. The north of England also was probably the scene of important movements during this interval; but the sea which covered the southwest district seems to have extended eastward without interruption, for Devonian rocks have been struck in borings at Turnford and in Tottenham Court Road, and come to the surface from beneath newer rocks between Calais and Boulogne. But on the

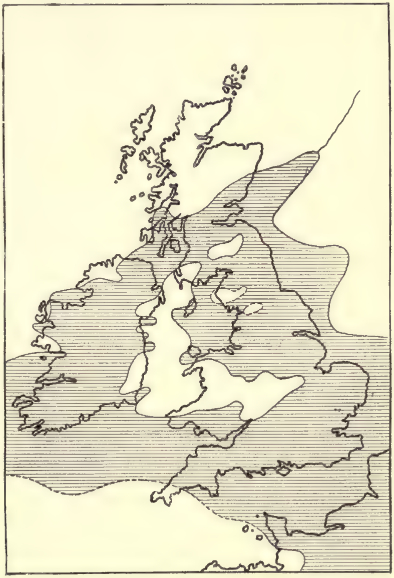


FIG. 133.—RESTORATION OF THE GEOGRAPHY OF BRITAIN IN EARLY CARBONIFEROUS (LIMESTONE) TIMES. (*After Jukes-Browne.*)

The sea is indicated by horizontal shading, the land is left white.

whole a large part of Great Britain and Ireland in the Devonian period must have been above the surface of the ocean.

The rocks of the Carboniferous system at the outset indicate a contrast of conditions somewhat similar to those afforded by the Devonian, with, however, a remarkable difference. In both there are marine deposits in the south and fresh water in the north; but in the Devonian the former occupy a small, the latter a large, area,

while in the Carboniferous it is exactly the reverse. The lower half of the Carboniferous system, wherever it is found, either in almost the whole of England or in Wales, is a marine deposit; but on both sides of the southern uplands of Scotland it is, in the earlier part, indubitably fresh water.

The Carboniferous system is divided into three great groups—the Carboniferous Limestone, the Millstone Grit, and the Coal Measures. These vary much in volume, but the total thickness of the system is often ten or twelve thousand feet. The first is mainly a marine deposit, the second and third are mainly fresh water, the evidence in either case being conclusive. But a detailed study of the rocks of the Carboniferous system in various parts of Britain throws some interesting light on the physical geography of the period. In South Wales the passage from the Old Red Sandstone to the Carboniferous Limestone is very similar, though in a reverse order, to that from the Silurian to the Old Red Sandstone. The rocks in the former case lose their red color, and pass into banded shales and limestones containing marine fossils. Presently, after about 150 or 200 feet, the shales disappear. The limestone in some districts on the north side of the Bristol Channel is often about 2000 feet thick, and occasionally more. Then it is replaced by banded shales, which are followed by the Millstone Grit and the Coal Measures. But the sea in which the pure limestone was deposited was evidently limited in area. On the northern margin of the South Wales coal field the limestone is reduced to about one-third of the thickness which it has on the opposite side; it attenuates toward the Forest of Dean, losing 1900 feet in about twenty-one miles; and at Newent, in Gloucestershire, it is gone, and the Coal Measures rest on Lower Old Red Sandstone; it also thins westward, for in Pembrokeshire it has similarly disappeared, since here Coal Measures overlie Ordovician rocks. In North Devon the limestones form only insignificant bands in a great mass of argillaceous rocks, while in South Devon they have died away. North of these places, in Eastern Wales and Western England, wherever information can be obtained, the limestones, as far as the neighborhood of the Wrekin, are wanting, and there is good reason to believe that all this area was a land surface. Near that hill and on the north of Charnwood Forest they set in, and thicken out northward, very rapidly in the latter case. In North Staffordshire they are said to be 3000 feet thick. But all the more northern part of Wales was land, for in the Clwyd valley and the north of Carnarvonshire conglomerates of considerable thickness lie at the

base of the limestone. Perhaps also the hill region of Cumberland and Westmoreland formed an island mass, for there similar, though thicker, beds of conglomerate occur. The sea—probably again locally interrupted at the Isle of Man—extended across the Channel to Ireland, and by far the larger portion of that country must have been submerged, for the limestones in places attain a thickness as great as in any part of England. From Dublin to Galway Bay, from Cork Harbor to Donegal, the Carboniferous Limestone extends, even now mostly in an uninterrupted sheet. Here and there some small island may have risen above the waves; the old continental land may have lain near at hand on the west; but probably the submergence was more complete than in any of the earlier periods of geological history.

The sea, however, over the English area was not only interrupted in the Midlands by a considerable promontory from Wales, or by a large island barely separated from that country, but was limited toward the north. As the Lower Carboniferous Measures are followed in this direction from South Derbyshire, not only do the upper shales increase rapidly in thickness, but also the limestones are found to lose their purity, and to be split up by intercalated beds of shale and sandstone. At last, on approaching the southern border of Scotland, even coal seams occur on the horizon of the Carboniferous Limestone, and at its base is a considerable thickness of strata (the Tuedian), to which a fresh water origin has been assigned. The same is true of the Carboniferous system in the central valley of Scotland; for an indubitably fresh water group, containing oil shales and some coal, with thick sandstones and even calcareous shales passing locally into a limestone, underlies the equivalent of the Carboniferous Limestone. In this region, however, the latter group is only partially marine. There is but little pure limestone, and generally even that is thickly interbanded with sedimentary materials which contain some important seams of coal. From these considerations it seems probable that even the thick marine limestones away to the south were formed in a sea the waters of which were clear rather than very deep. Probably the earlier half of the Carboniferous period was a time of quiet subsidence, when the border district of the old continental land was broken up into island groups and its larger valleys were converted into fjords, the heads of which arrested the sand and mud borne down by the rivers which drained the more mountainous lands.

At last a change occurred. The area on which only the *débris* of

organisms had accumulated was again brought everywhere within the reach of sediment, and the Millstone Grit consists of detrital materials, especially of sandstone. So the rocks continue to the end of the period. Beds of coal are intercalated among the sediment, and may occur even in the Millstone Grit; as a rule, however, they are associated with the lower and middle part of the Coal Measures, especially the latter. They, of course, are of organic origin. The actual coal seams, even when added together, do not amount to a very great thickness, but the aggregate of the sand and sandstones in the upper part of the Carboniferous system is very large, perhaps sometimes not less than 10,000 or 12,000 feet. As has been already said,* these beds were probably formed on a swampy delta. The sea, however, cannot have been far away, for at two or three horizons the dark muds in several parts of England contain a number of marine fossils. This lowland—probably formed by a group of confluent deltas, as on the northwest of the Adriatic—covered a still larger area than the sea by which it was preceded. Land which had risen above the latter was overwhelmed by the sediment and overgrown by the coal bog. The vast plain apparently stretched almost without break over England. Probably it was only imperfectly interrupted by the southern uplands of Scotland, and ran up to the feet of the Highlands and the mountains of Donegal. It must have extended at least from the Welsh border over almost the whole of England, for beds of this age are known to underlie Burford, in Oxfordshire, and coal has been struck full 1200 feet from the surface at Dover. Similar rocks very probably extended over the greater part of Ireland, but, unhappily for the prosperity of that country, the coal fields are now few and scattered. Time and Nature have added to the wrongs of Ireland by stripping it of the rocks which might have been a source of material wealth.

Professor Hull pointed out, several years since,† that the sedimentary materials of the Carboniferous system exhibited a tendency to become thinner in the northern districts toward the south-east or south, in the southwestern districts toward the east. From these facts he inferred the existence at that period of sundry large rivers—of at least one in the former region flowing from the north-west or north, and of one in the latter flowing from the west. There may have been yet more, but such masses of thick and wide-spread sediment could only have been supplied by rivers compared

* See pp. 177–180.

† *Quarterly Journal of the Geological Society*, vol. xviii. 1862, p. 127.

with which those of England in our own day would seem little more than brooks.

During all this time volcanic outbursts were rare and local * in England, but they continued actively in Scotland. The region of the central valley must have been dotted over with cones and craters as thick as the uplands of Auvergne; the majority of these ejected basaltic ashes and lava. In Arthur's Seat, on the shores of the Firth of Forth, on the east coast of Fife, and elsewhere, the relics of these ancient volcanoes may be studied with comparative ease. They had begun in the preceding geological period, as has been said above; they continued through the long ages of disturbance and denudation which introduced the Permian period, and in this they seem to have finally sputtered themselves out and become extinct.

Much controversy has arisen among geologists as to the relation of the Carboniferous to the Permian system. In some countries it is hardly possible to separate them, while in others the latter seems severed from the former by a long interval, and to be clearly connected with the Trias. In England the evidence is conflicting, being in some respects favorable to one view, in some to the other. This, however, is certain, that in many places a great break exists between the Carboniferous and the Permian, and even thousands of feet of rock were removed by denudation from the former before the lowest beds of the latter system were deposited. The existence of a break between it and the Trias is much less clearly proved. In the north of England Permian beds occur on both sides of the Pennine chain. On the eastern they are only a few hundred feet in thickness, and consist chiefly of limestones, often magnesian; † on the western mainly of sandstones and shales, the calcareous element being comparatively small. The strata appear to attenuate toward the south, and were limited, in the opinion of Professor Hull, by a barrier which extended diagonally across the plain of Cheshire. South of it rocks of Permian age again set in, though they are not largely exposed at the surface. In this region they consist almost entirely of sandstones and marls, with some breccias and conglomerates. From the latter it is clear that many of the older rocks were being denuded, including various parts of the Carboniferous system,

* There were some in Devonshire, and occasional discharges of lava and ashes on the bed of the sea in Derbyshire.

† Some of which makes an excellent building stone—used, for instance, in the cathedral and walls of York, and in the Jermyn Street Museum and the Houses of Parliament, the last sometimes being of an inferior quality.

even down to the limestones, and that such districts as the Charnwood Hills rose well above water. Professor Hull also thinks that the Permian rocks of the Midlands represent only the deposits of the earlier part of the period, and are anterior, as a whole, to the limestones of the northeast. Probably they never extended much further south than the Malvern Hills, and the remainder of England in this direction was supposed to have been dry land. But of late years it has been maintained that a great mass of sandstones, breccias, and marls, with some associated volcanic rocks, which underlies the indubitable Trias of Devonshire, does not form part, as was once supposed, of that system, but is really Permian, and this view appears now to be meeting with general acceptance.

One serious difficulty which confronts us in any attempt to restore the physical geography of Britain during the Permian period is the date of the uplift which formed the Pennine Range. By some geologists this is placed between the Carboniferous and the Permian; by others between the latter and the Trias. If the former view be correct, the sandy beds of the northwest and the calcareous beds of the northeast must have been deposited in separate basins; but in the other case they might have been parts of a continuous deposit, which became more free from sediment as its distance from the western land increased. The details of the controversy are in some respects too technical for discussion in these pages, so that we must limit ourselves to the statement of certain facts concerning which there is a general agreement.

The Carboniferous period was closed by a most important series of earth movements, which not only affected the whole of England, but also a very large adjoining area. All of this was thrown into a series of anticlinal and synclinal folds, and toward the south a mountainous mass was formed, which, even if we do not apply that term to anything north of the Bristol Channel, "was not less than 300 miles wide across the strike of the folds. To its altitude we have no clew, but its breadth must have exceeded that of the Alps, and it probably extended westward beyond the southwestern angle of Ireland, while traces of it can be followed eastward to beyond the Rhine—more than 35° of longitude. Yet the sea now flows where some of its highest summits may have risen; its only record is preserved in the low plateaus and comparatively humble hills of Cornwall and Devon, of the Channel Islands and of Brittany."*

* The author, *Quarterly Journal of the Geological Society*, vol. xliii. 1887, p. 320.

The general direction of the folds thus produced in the region just mentioned is roughly east and west, but in the northern half of England they trend more nearly east-northeast.

These disturbances cannot but have affected most materially the physical geography of Britain. They probably were connected with the numerous outbreaks of basaltic and other volcanic rock in many parts of England, Scotland, and Ireland, and with the protrusion of

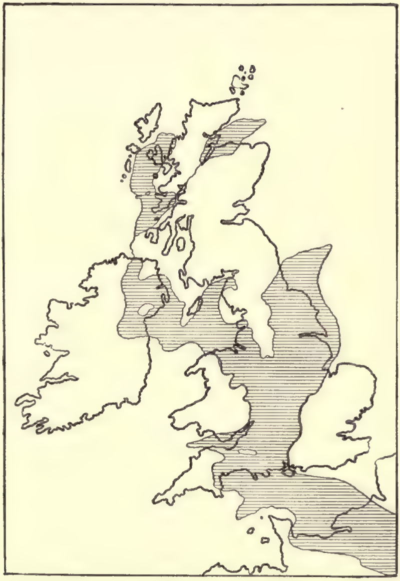


FIG. 134.—RESTORATION OF THE GEOGRAPHY OF BRITAIN IN KEUPER TIMES. (*After Jukes-Browne.*)
Water and land as in Fig. 133.

the great granitic masses in Devon, Cornwall, and Brittany. These possibly may be only the cores of ancient volcanoes; but if so, the cones which once crowned the hills of Dartmoor must have been on a grand scale. Certain it is that, as already said, the Carboniferous rocks in some places were largely denuded before the Permians began to be deposited.

The Permian limestone in the northern area contains marine

fossils; but it has been suggested that these are indicative, not so much of an open sea, as of one like the Baltic or even the Caspian. The Triassic deposits, it is generally agreed, are not marine in origin. On the whole, they overlap the Permians, but the break between these is not conspicuous. This, however, is clear—and it seems a point of some importance—that, at whatever date the Pennine Range was upraised, the forces which brought it into its present form must have acted, roughly, from east to west, or at an angle of from 70° to 90° with those which produced the admittedly pre-Permian folds. Movements, however, so very different in direction are not likely to have been consecutive, but were probably separated by a long interval of time. Hence, although much difference of opinion still prevails, and the earlier date of the Pennine Range, perhaps, finds on the whole more favor, I incline to the other view, and think that in Permian ages a sea extended across the northern part of England from east to west, though it may have been interrupted by islands, and was probably shallow.

The Trias in England is generally divided into two groups, called respectively the Bunter and the Keuper; but even here we do not escape from difficulties. That it passes up gradually into the Jurassic system is universally admitted, and there is a general agreement as to the circumstances under which the Keuper was formed. But as to the history of the Bunter much controversy still prevails. This group, in the part of England north of the Malverns, is known to exist over most of the lowland district between the hills of Wales, of the Lake District, and of the Pennines, to pass round the south end of the last named, and to follow their eastern flank to the neighborhood of the Tees.* On this side probably it does not extend so far east as the coast of North Lincolnshire, but occupies a kind of channel between the Pennine Hills and some rising ground (now concealed beneath newer rocks); it hardly does more than reach Leicestershire, Warwickshire, and the middle of Worcestershire. On the western side of this region the Bunter consists of two wedge-like masses of sand parted by a similarly shaped bed of pebbles, which generally extends slightly beyond the other two. The pebble bed, however, is split up by thin bands of sandstone, and becomes more arenaceous in the neighborhood of the Irish Channel. The Bunter group as a whole attains to a considerable thickness. In parts of

* There is some Trias on the southern and western margins of the Lake District, as well as near Carlisle; but as the amount is comparatively small, and geologists are not in accord as to its correlation, we must abstain from discussing it.

Cheshire and Lancashire this varies from one to two thousand feet, and in Staffordshire the pebble bed alone is often three or four hundred feet thick. In any attempt to unravel the history of this group two questions present themselves for settlement—namely, how the materials were transported, and whence they were derived. It is generally admitted that the Bunter deposits are not likely to be of marine origin; they are quite without fossils,* and much resemble the pebble beds of Oligocene age in Switzerland (called *Nagelfluh*), which are known to be fresh water. They have also a considerable resemblance to the coarse gravels which cover all the lowlands around the Alps. It is, however, uncertain whether they should be considered lacustrine deposits, or distinctly fluviatile, like the last-named gravels. Speaking for myself, I find the tripartite arrangement very difficult to explain on any other hypothesis than that these wedge-like masses are true river deposits, the produce of streams which first increased and then again decreased in velocity. That these were broad and important is indicated by the volume of the deposit, and that the average rate of the current was from two to three miles an hour is proved by the size of the pebbles.

But from what region have these traveled? To this question also different answers are returned, but the following are the principal facts of which account must be taken in framing an hypothesis: The Bunter beds consist partly of sandstone (composed chiefly of quartz, with occasionally mica and felspar), partly of pebbles. The sandstone, on careful study, indicates that it has been formed by the destruction of a large mass either of granitoid rock or of some older sandstone. Its volume, on a rough approximation, is equal to that of an unbroken range of hills 65 miles long, 4 miles wide, and 5000 feet high. Even the pebbles probably represent a mass of rock equal to four cubic miles, or a similar chain of hills 20 miles long, 2 miles wide, and 1000 feet high.† It is therefore evident that, whether the sandstones were derived from older sandstones and the pebble beds from more ancient conglomerates, or whether both were obtained directly from the parent rocks, they represent the *débris* of a large land area, the produce of great and powerful streams. Such deposits cannot be furnished by miles of reefs and skerries or by

* Some of the pebbles contain fossils, but these, of course, belong to rocks of an earlier date. So far as the writer is aware, no contemporaneous fossils have been found in the Bunter beds of the northern half of England.

† The author, Presidential Address to Section C, British Association, Birmingham, 1886.

chains of islands moderate in size and elevation — that may be regarded as a certainty if geological principles have any value. Let us, then, turn for a moment to the pebbles to see what further light they can throw on the question. A limited number consist of Palæozoic rocks, ranging upward from the Ordovician or Cambrian; not a few are vein-quartz. This group gives little help—such a rock, for instance, as a chert, of Carboniferous Limestone age, may have come from any quarter of the compass. One variety, however, affords some hope of discovering its place of origin. It is a hard grit or quartzite, containing organic remains, which resembles a fossiliferous rock at the Lickey Hills and certain pebbles in a conglomerate (of about the same age) at Budleigh Salterton, in Devonshire. But though these pebbles are far from common, the former area seems too limited in extent to have been the center of a dispersion which has been traced at least as far as the neighborhood of Nottingham, and the latter seems excluded by the fact that at this epoch the northern and southern districts appear to have been separated by a neck of land. So none of these pebbles furnish evidence of any value; but still a considerable number of others have been identified. One of the commonest rocks in the pebble bed is a quartzite, so compact and hard as to break sometimes with almost a smooth surface. It is occasionally liver-colored, not seldom reddish, more commonly various shades of gray, from almost white to dark. This quartzite does not present more than a superficial resemblance to any of those known to occur in England or Wales, such as the rock at Hartshill, the Wrekin, the Lickey, or the Stiper Stones, but it is exactly like the great mass of basement Cambrian quartzite which is so conspicuous a feature in the scenery of the Northwest Highlands — a rock which indubitably has furnished myriads of pebbles to the conglomerates of Old Red Sandstone and early Carboniferous age in Scotland. Besides this quartzite, pebbles occur of a peculiar hard quartz-felspar grit, which often might be mistaken for a granite. No such rock can be found above the surface anywhere in England or in Wales, but it exactly corresponds with the Torridon Sandstone of the Northwest Highlands, which also occurs in the above-named Scotch conglomerates. Again, pebbles of rather compact igneous rocks, mostly varieties of felstone, are far from rare in this Bunter deposit. These, as a rule, differ from any felstone known either in Wales or in England,* but they closely

* Some of the Cornish rocks present the nearest resemblance to these, but the likeness is not strong; this area, as stated above, cannot have supplied materials.

resemble the felstones which, as already said, are so abundant in the hill regions of Scotland, and were mostly erupted in Old Red Sandstone times. They also are very common in the above-named Scotch conglomerates.

The wedge-like shape of the Bunter deposits, with their thick ends pointing to the northwest or north, indicates that the materials have traveled from that direction. Here, however, a difficulty is raised, for the pebble beds in the neighborhood of the Mersey, though more than twice as thick as they are in Staffordshire, not only are much more sandy, but also the pebbles themselves run distinctly smaller. We might have expected, it is urged, that the materials would have become coarser in approaching the source from which they were supplied. This, no doubt, is a real difficulty, and it has so much weight with some geologists that they maintain the general drift of the materials to have been from the south or the east. But at the present time no rocks of the required kinds can be found in either of these directions; and when advocates of these hypotheses fall back, in order to support them, on ridges which they assume to be buried beneath later sediments, we may reply that our knowledge of the physical geography of the district to the south enables us to affirm that any high ground in that quarter must have been far too restricted in area to have supplied the requisite quantity of materials, and that not only is there no evidence of the existence in early Secondary times of any land in the east capable of feeding large rivers and supplying huge masses of sand and gravel, but also all that is known is opposed to the idea. We find, however, both in later Primary and in earlier Secondary times, distinct evidence that a continental land once existed in the northwest, and that materials drifted from this quarter. Seeing, then, that the argument founded on the size of the pebbles is directly contradicted by that resting on the northern thickening of the deposits, these may be dismissed as mutually destructive, and the hypothesis of a northern derivation is left in possession of the field.*

The sands and sandstones of the Bunter group are often false-bedded, and occasionally contain well-rolled grains in considerable abundance, the latter being indicative of the action of wind.† We

* It must not be forgotten that rivers have a tendency to bifurcate and spread out in the area of their deltas; thus the distribution of pebbles may have been more general in the Midland area, and may have been limited to a few main channels (which have not yet been struck) in the more northern one. Here the sand would be mainly a flood-time product.

† See p. 85.

may picture to ourselves a highland or mountainous region, like another Scandinavia, rising on the west and northwest of the British Isles. From the portals of its hills issued full-flowing rivers, laden with sand and pebbles, which were deposited on the lowlands, as they have been, and still are, spread out at the foot of the Alps. On this mountain region the rainfall may have been heavy ; but the frequency of the wind-worn grains and the wide extension of the sands suggest that the plains may have been arid and barren. What became of these rivers we cannot yet say. They may have lost themselves in deserts, like some rivers at the present time ; but it is more probable that their waters passed out through some comparatively narrow channel, now hidden under the southern part of England, to join a sea which at this time covered a portion of Central Europe.*

In the present state of our knowledge it is difficult to say much about the Bunter deposits of the southwest of England. If the above-named breccias, sandstones, and marls really belong to the Permian period, the pebble bed already mentioned as occurring at Budleigh Salterton, which does not exceed 150 feet in thickness, and is usually less than 100 feet, is almost the sole representative of the group in question. In this bed well-rounded pebbles of quartzite or hard grit are common, which contain fossils. Of these the majority have been assigned † to Lower Devonian rocks, and the remainder in part to the Bala, in part to the Arenig. Such rocks occur more or less commonly in Devonshire, Cornwall, and northwestern France, so that these pebbles were probably brought by streams which flowed from the west or southwest—that is to say, from a prolongation in the direction of Armorica of the great land area which has been already mentioned.

The Keuper group consists of sandstones of moderate thickness, followed by a great mass of marls or clays. The former vary from alternating layers of sandstones and marls to good solid sandstones, which are excellent for building. The marls are red in color, with greenish-gray bandings ; they are locally interrupted by thin sandstones, and in the south of England by breccias. The last named are found at different elevations encircling the hilly districts, such as the Mendips, and are composed of fragments from their materials,

* It is commonly admitted by geologists that the general direction of the drainage for a considerable time immediately after the Trias was in this direction.

† By the late Dr. T. Davidson, "Monograph of British Fossil Brachiopoda," vol. iv. p. 337.

generally Carboniferous Limestone, which has often become dolomitic. Evidently these are shore deposits, formed in comparatively quiet water. Ripple marks, sun cracks, and rain prints are not unfrequent in certain of the sandstones; the footprints also and bones of saurians and amphibians, with the remains of fishes and of plants, are found, though they are not common. The marl is almost unfossiliferous, though the breccias have produced a few relics of interest, but it frequently contains gypsum and rock salt or brine.* Occasionally a slight unconformity may be detected at the base of the Keuper, and a marine deposit † is intercalated in Eastern France and in Germany between it and the Bunter, which, however, is not represented either in England or in the northern part of France. The lower part of the Keuper seems to indicate a continuance of conditions generally resembling those which prevailed in the Bunter, but the marls with their gypsum and rock salt are similar to the deposits of an inland sea. That the Keuper marls were formed under such conditions is now regarded as beyond doubt. At that epoch a large inland sea must have covered a considerable part of England—in shape something like the letter Y. The arms were parted by the Pennine Hills; on one these formed the western shore, the eastern limit being rising ground in the direc-

FIG. 135.—SUN CRACKS AND FOOTPRINTS (CHEIROTHERIUM), TRIAS, HESSBERG (THURINGIA).

The hind feet larger than the fore, and more than one animal has left its mark.

* No mollusca have been found, but the cases of a few small crustacea (Estheria), which are commonly fresh water, occur locally.

† Called the *Muschelkalk*. (See the next chapter.)

tion of the German Ocean; the western arm passed between the Cambrian and Cumbrian Hills, in the direction of the Irish Sea, at least to Antrim. This huge salt lake in many places, at any rate during part of the time, must have been studded with groups of islands.* The Mendip Hills, the Quantocks, and many other undulating masses in Somersetshire and the neighborhood rose above its surface, as the Steep Holm and other islands now interrupt the Bristol Channel. If we would form a picture of this region in the Keuper age, we have only to broaden the area of the Severn Sea, as it appears sometimes even now, when,

> 'Tis water here and water there,
> And the lordly Parret's way
> Hath never a trace on its pathless face
> As in the former day.

The salt lake at one time must have covered much of the lower ground in this part of England, between the uplands of Cornwall, Devonshire, and South Wales. Its western shore was doubtless formed by the hills of Wales, while on the east it was probably bounded by an upland region, now underlying Middlesex, Essex, and the adjoining districts, to which we shall again refer. In the Midlands the hills of Charnwood Forest, at least for a considerable part of the period, formed a lonely island group, for here in many places the marls can be seen resting upon the rugged surface of the old land, where they have filled up inequalities and glens. They often contain blocks of stone, which lay loose on the surface myriads of years ago, just as these are still scattered on any mountain side. Triassic deposits also occur on the western shore of Scotland, and in the neighborhood of the Moray Firth. The map on p. 369, a reduction of one made by Mr. Jukes-Browne, gives a general idea of the area which must have been occupied by this great salt lake, and of the probable connection of these northern outliers with the principal sheet of water.†

Into this lake, doubtless, the rivers already mentioned, with all the streams, great and small, from the borderland, discharged their waters. Any coarse material, as is usual in lakes, would be deposited in the immediate neighborhood of the shore; only the finer mud would float for any distance before it sank to the bottom. So

* See a map by Professor Lloyd Morgan, published in Mr. Jukes-Browne's "Building of the British Isles," ch. viii.

† A. J. Jukes-Browne, "Building of the British Isles," ch. viii.

the Keuper clay, as might be expected, is generally very uniform in character. From Antrim to Devonshire specimens might be collected so similar that they would be practically indistinguishable. At present the exact position of the barrier which toward the southeast separated this salt lake from the sea cannot be ascertained with precision. Probably it was comparatively low, for no marked disturbances appear to have accompanied the return of marine conditions.

The Keuper deposits in the region of the Eastern Alps are distinctly marine, and they are succeeded by an important mass of strata, often 2000 feet thick, of like origin, which is named Rhætic, and is sometimes treated as a separate system. The Keuper, in many parts of England, also passes up into beds which contain fossils and are evidently of this age; but these are very thin, commonly not exceeding 30 or 40 feet. The two groups are not sharply separated. The Keuper loses its distinctive color—becomes first gray and then dark—and the characteristic Rhætic fossils make their appearance. So these beds in England are not generally treated as a separate system, but are grouped with the Trias. There can be little doubt that the sea gradually overflowed the barrier, and opened a communication with the salt lake. The waters of the latter probably—as is usual in such cases—were almost, if not quite, lifeless; but now by degrees their saltness would be reduced, and they would become habitable, and be invaded by organisms from the outer sea. But by this time the Rhætic fauna itself was becoming enfeebled; and no very long time after the sea once more ebbed and flowed over parts of the British Isles, this addition to its domain was invaded by the young and vigorous fauna of the coming Jurassic period. All through the remainder of the Secondary era we shall find the march of life to have been from the southeast. The Norman and the Saxon did but follow a path which had been trodden by the animal creation long ages before man had appeared upon the globe, for even in these distant times the British seas were always peopled by colonists from France and from Germany.

The Jurassic system in Britain is generally subdivided into the Lias and the Oolites. The former is a mere *patois* word adopted into science; the latter denotes a peculiarity in some of the limestones, which are made up of small rounded grains like the "hard-roe" of a herring. They are equally objectionable, but have to be tolerated. Both the Lias and the Oolites are divided into a Lower, Middle, and Upper. The beds vary considerably in mineral char-

acter and in thickness—perhaps about 2500 feet may be taken as a rough average approximation. Jurassic rocks stretch from the coast of Dorset diagonally across England to Yorkshire, but only one or two fragmental patches of Lias indicate the extension of an arm of the sea toward the northwest. Here, however, much has been removed by subsequent denudation, so that we may fairly assume that the sea, like the preceding salt lake, extended at least as far as Antrim. At first sight it might be supposed that the Jurassic rocks indicated conditions of deposit extremely diverse, but a further study leads to the conclusion that, on the whole, they are very closely connected. The rocks are sandstones, clays, and limestones; the first, as a rule, being rather limited in extent and thickness. Putting them aside, and regarding the Jurassic system of Britain as a whole, we find it to consist of three great masses of clay, followed in each case by a zone in which, though some interesting variations occur, limestones dominate. These clays are the Lias (regarded as a single deposit), the Oxford Clay, and the Kimeridge Clay.* To the first of them succeed the Lower or Bath Oolites; to the second, the Oxford Oolites; to the third, the Portland Oolites. Of these three clays the Lias obviously was deposited as a whole at no great distance from land. Fronds of ferns, leaves of plants, and pieces of wood are not rare; a few land shells have been found in deposits of this age in Somersetshire; insects are not very uncommon in some localities. It becomes sometimes sandy, sometimes calcareous. A sea—the outlines of which probably corresponded roughly with those of the Keuper Lake—received very similar materials † from the same sources. The same is probably true of the Oxford Clay and the Kimeridge Clay, though indications of the proximity of land are not so frequent or so marked. Very likely these dark clays were partly supplied from the shales of the Carboniferous system, for in the Pennine Hills and other parts of Britain its rocks must have undergone much denudation during this period.

The Lower Oolites are not nearly so thick as the Lias, and are very variable; this remark also holds good of the remainder of the Jurassic system. Important limestones occur in the southwest of England, as in Somersetshire and Gloucestershire, and in the north-

* The second and the third may be roughly estimated at about 500 feet in thickness; the first is sometimes more than twice this amount.

† The Lias clay is generally dark colored, and the Keuper red, but this difference is only due to the exceptional circumstances under which the latter was deposited, and does not indicate a real difference of detrital material.

east, as in Lincolnshire. In the former district two such beds exist—that quarried, for example, near Cheltenham, and that all about the town of Bath. In the latter we find one, that called the "Lincolnshire Limestone." All these generally are very fine limestones, composed almost wholly, directly or indirectly, of organic remains. The other beds in this group are varied in character, and indicate deposits in shallower water, and occasionally estuarine conditions. These seem to have been almost permanent in Yorkshire, for plant remains are often abundant, and even thin seams of coal occur. The "Cheltenham" Limestone gradually disappears as it is traced to the northeast, and in south Northamptonshire its position is marked by a slight unconformity, but in the north of the county the "Lincolnshire" Limestone comes in at this horizon, and attains, after a time, a thickness of seventy to eighty feet, again thinning so as to be very feebly represented in Yorkshire. The "Bath" Oolite is more persistent, but in the Midland and northern counties it is reduced to a bed only a dozen or twenty feet thick, which is of little or no value to the quarryman. It is therefore evident that the land must have been very near to the north of Yorkshire.

The Oxford Oolites indicate a recurrence of similar conditions. Limestones extend from Dorsetshire to Oxfordshire, in which county they cease rather abruptly, and the clay underlying them passes on till it graduates upward into the Kimeridge Clay. Except for a little insulated patch of limestone, obviously an old coral reef, which occurs between Cambridge and Ely,* this continuous mass of clay extends from North Oxfordshire to South Yorkshire, where limestones are again found.

In Dorsetshire the Kimeridge Clay is succeeded by the Portland Limestone,† which may be traced to Buckinghamshire. North of this county for a considerable distance a break exists in the record, the result of an ancient denudation. In Yorkshire, however, the Kimeridge Clay passes upward into one which contains a few fossils of Portlandian age, and clays continue till we reach the base of the Cretaceous system. The Portland strata in the south of England are succeeded by estuarine and fresh water deposits, called the Purbeck group. These indicate a river delta, and show that the land had risen. In some places an old soil, containing the stems of conifers and the stools of cycads, can be found, which is a remnant of an

* At Upware in the Fens, on the right bank of the Cam.

† In this county a bed of sand lies between it and the Kimeridge Clay, but the group exhibits much variation.

actual land surface. The river delta may be perhaps traced into Buckinghamshire, north of which it, like the Portland Limestone, is lost.

A number of deep borings have been made in the southeastern counties which throw much light on the geography of Britain during the Jurassic epoch. At Netherfield, near Battle (north of Hastings), after going through Purbeck strata and some sandy beds representing the Portland, the Kimeridge Clay was traversed, followed by a representative of the Oxford Oolites (mostly clayey), and then the boring was abandoned, at a depth of about 1900 feet from the surface, while it was still in the Oxford Clay. This spot, therefore, indicates a point in the channel along which the finer sediment was discharged by the "main sewer" of England in Jurassic times. At Chatham Oxford Clay was pierced, but all the overlying Jurassic

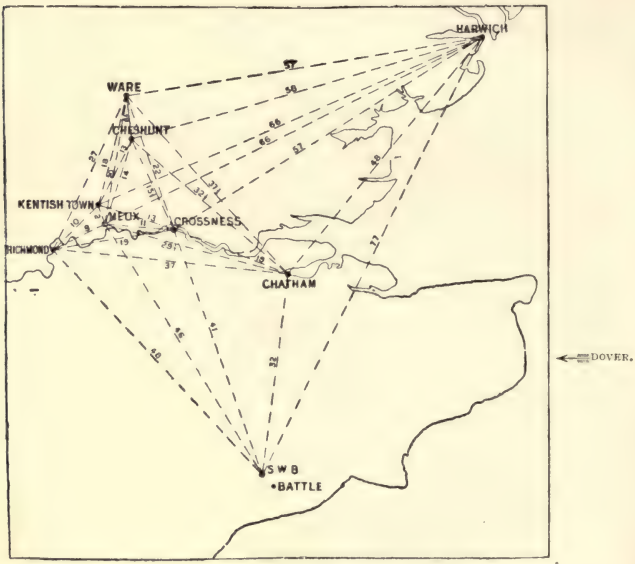


FIG. 136.—MAP OF DEEP BORINGS IN THE SOUTHEAST OF ENGLAND (*Whitaker*).

The figures give the distance in miles (the Streatham and Dover borings have been completed since the map was made ; the arrow points to the position of the latter).

rocks were missing. In the borings at Streatham, Richmond, Tottenham Court Road, Kentish Town, Crossness, Turnford, Ware, and Harwich various Palæozoic rocks were struck beneath the bottom beds of the Cretaceous system, at depths of from 800 to 1100 feet. In all these deposits of Neocomian age were either wanting or very thin. In most cases Jurassic rocks were also absent, but at Tottenham Court Road, Richmond, and Streatham a very moderate thickness (less than 90 feet) of Jurassic rock was found, which is referred to the age of the Bath Oolites. Two inferences follow from these facts: one, that the Jurassic sea was bounded on the east by a considerable mass of land which lay beneath the lower part of the present valley of the Thames, and extended for some distance northward (Chatham, probably, is situated over its southern slope, and Hastings above the channel which separated it from the western land); the other, that the most marked submergence in Jurassic times was during the Lower Oolite and contemporaneous with the deposition of the Bath Limestone.

We may therefore conclude that a downward movement continued throughout the greater part of the Jurassic period, the rate of which, however, was probably not quite uniform. Each of the limestones may indicate a time of slightly more rapid depression, when the sea would invade the valleys and convert them into fjords, at the head of which the mud brought by the river would be deposited. These, by degrees, would be filled up and become low plains, till at last the rivers once more emptied themselves directly into the sea, and their mud was drifted away by tidal and other currents. The same result might also be produced by slight movements in an opposite direction. If, at the end of a time when limestone had been forming, an elevation of a few yards were to occur, a fjord would be replaced by dry land, and the river as it hurried through the incoherent mud, so recently deposited, would quickly sweep it out to sea. Thus sediment such as that of the Kimeridge Clay may have halted at least once on its outward journey. On the whole, however, a continuous movement in one direction seems the more probable, though it need not have been equally rapid in every part of the area affected.

Deposits of Jurassic age occur in Scotland, both on the shores of the Moray Firth and in the islands of the western coast, such as Skye and Mull. On the east they afford a fairly continuous section into the Upper Oolite, but on the west the record ends with the Oxford Clay. These deposits indicate the same fluctuations of ter-

restrial, estuarine, and marine conditions as are shown in the Lower Oolites of Yorkshire, and they were obviously formed in the vicinity of an irregular island-studded coast very like that of Western Scotland at the present day. Now that is washed by the Atlantic Ocean, but this hardly can have been the case at so early a period as that of which mention has been made. Only a land of almost continental extent could have supplied such great masses of sediment as are embedded in the Jurassic system. This land must have been larger than Scandinavia, and hardly can have been less hilly. The channel in which the Keuper Lake was lodged, as already said, was prolonged for a considerable distance northward, and, as the land sank, it would be overflowed by the sea. It would then form an estuary, the head of which, no doubt, would be a considerable distance from the open ocean. It is possible, however, that the other valley which must have joined the eastern arm of the Keuper Lake may have been accessible somewhere by a low pass, which at times may have been submerged, so as to allow of a complete marine circulation, as there is through the Lofoten Islands on the coast of Norway.

The Neocomian follows the Jurassic system. On the continent of Europe, as in the region of the Swiss Jura, it attains a great thickness—perhaps as much as 9000 feet of rock—and is subdivided into four groups, each of which has received a name. In England, however, the deposits of this age do not cover a very large area, and are often comparatively thin, although they are generally full of interest. The succession is complete in Yorkshire and in the southeastern districts. In the former a few hundred feet of clay which resembles in color and is apparently continuous with the underlying Jurassic Clay represent the whole thickness of the continental Neocomian, with its fine, hard, cream-colored limestones. These deposits may be traced at intervals southward from Speeton Cliffs into Lincolnshire, where they become sandy, and were probably approaching a coast line, of which more presently. In the southeastern district the Neocomian system consists of a lower and larger fresh water group called the Wealden, and an upper marine group called the Lower Greensand, the last named being well exhibited in the Isle of Wight and in various parts of Kent and Sussex. The existence of a great river was indicated by the estuarine and fresh water deposits of the Purbeck; this, in the Weald, had evidently taken possession of a larger area in the southeast of Britain. Deposits of fresh water origin can be traced from

the Dorset coast to the neighborhood of Boulogne, a distance of 320 miles from east to west. The breadth of the delta, which was probably more or less triangular in outline, with its apex pointing westward, is less easily ascertained, but the deep borings already mentioned prove that it did not reach the present valley of the Thames. It cannot, however, have extended less than 50 or 60 miles. In parts of Sussex these fresh-water deposits attain a thickness of nearly 2000 feet, and at Swanage, in Dorsetshire, are estimated at 1800 feet; but they thin rapidly to the west, and have not been found beyond Ridgway. In the lower half sands predominate; the upper consists of clays, with thin bands of fresh-water limestone. If it had been possible to have stood on the southern edge of the upland which lies buried beneath the feet of Londoners, in the days when the sea had but recently yielded place to the river, we should have overlooked a vast marshy plain lying some two thousand feet beneath, and stretching southward as far as the eye could see. Dense forests, reedy jungles, quiet pools, in varied iteration, no doubt saved the vast fen from absolute monotony, and here and there the broad reaches of the river gleamed in the sunshine as it wound its way seaward from the western uplands; parted probably into diverse channels, and sometimes after heavy rains overflowing its banks and making the whole valley into one great lake.

All this time, as is the wont of deltas, the land must have been sinking, while the river struggled to build out the sea; but finally the victory remained with the latter, and it once more occupied the southeast of England. The Lower Greensand group is about 800 feet thick in the Isle of Wight, and half that amount in Kent. As the name implies, its beds are generally sandy, and the uppermost subdivision is a fawn-colored sand, often very ferruginous. This may be traced diagonally across England, from Dorsetshire into Lincolnshire, and in the Central Midland and the East Anglian districts it rests upon an eroded surface of the older Jurassic rocks. But it is generally missing beneath the London area; so that the upland already mentioned must have managed just to keep its head above water, even at the end of the epoch, although it cannot then have been more than a low island, and these sands were no doubt deposited in a rather shallow channel with fairly strong currents, which at last connected the Yorkshire sea with that covering south-eastern England.

The lower part of the Cretaceous system proves to be inconstant

in character as it is followed across England from south to north; but the upper, and far the larger, portion is generally very uniform. At the base, in the southeastern districts, a clay is found, called the Gault, which is followed by a calcareous, more or less sandy, deposit, usually containing numerous glauconitic grains (Upper Greensand), which passes up into the thick mass of soft white limestone known as the Chalk. The first and second vary in thickness, but together often amount to from 150 to 250 feet; the Chalk sometimes attained, in the more eastern parts of England, to a thickness of over 1000 feet. It is rather marly in the lower part, but after a time it becomes a very pure limestone, consisting, as already stated, almost wholly of organisms and their *débris*.* Bands of flint are frequent, and these usually occur in the upper half.

As the Gault and Upper Greensand are followed toward Bedfordshire, the latter rock disappears and the top of the former begins to show signs of denudation. In the Cambridgeshire district the upper part of the Gault has been washed away, and the base of the marly chalk is formed by a seam containing green grains and phosphatic nodules or fossils, many of which indubitably have been derived from the Gault. But in Norfolk, as we may see in the cliff at Hunstanton, the brown ferruginous sands belonging to the uppermost part of the Neocomian system are covered by a bed of chalk blood-red in color. This is only about four feet thick, and it is followed by the usual slightly marly white chalk. Here, then, this thin seam occupies the interval which usually is filled by the whole of the Gault and the Upper Greensand together. It may be followed through Lincolnshire into Yorkshire, thickening slightly as it goes, until when it comes to the sea at Speeton Cliff it has reached about 30 feet.

The Gault, as it is followed westward into Dorsetshire, loses its clayey character and resembles that of the Upper Greensand; so that it can only be identified by its fossils—as, for instance, is the case at Blackdown, in Somersetshire. In the west of England the Chalk is represented merely by a few outlying patches, generally belonging to this lower part. But deposits of unworn flints, forming a sort of gravel or breccia, may be found here and there lying upon the old Primary or the crystalline rocks as far as the Scilly Isles. They are the residues of much greater rock masses, from

* The white chalk often contains full 98 per cent. of carbonate of lime; the gray, or less pure, chalk contains 4 or 5 per cent. more of earthy matter. (See p. 4.)

which the solvent action of water has removed the intervening limestone, and they indicate that the sea in which chalk was deposited extended far away to the west beyond the last patch of this rock which at present remains.

The foraminiferal ooze which is dredged up from the deeper parts of the ocean * resembles the white chalk more nearly than any other rock. We must not, however, too hastily conclude that the waters in any part of the Cretaceous period rolled full a thousand fathoms above the present site of the valley of the Thames. As will be seen when we review the past physical geography of Europe, the area occupied by Chalk is more restricted than it should be if this rock had been formed in oceanic depths. The fauna also of the Chalk, regarded as a whole, is not indicative of such conditions. Some of its members might have lived at depths hardly exceeding 100 fathoms; most of them are not, strictly speaking, "abyssal." As Professor Prestwich says,† at the conclusion of an excellent review of the evidence, the depths of this sea hardly can have exceeded 500 fathoms, and may not have been more than from about 200 to 300. But its waters must have been unusually clean. Hence the sinking of the land which for so long had been in continuous process, had now sufficed to put an end to the supply of sediment and to the results of terrestrial denudation on a large scale, which hitherto have so constantly asserted themselves. In the Keuper marl, the clays of the Lias, the Oxford and Kimeridge deposits, and the Weald, we have indications of physical conditions resembling those which must have produced the thinner deposit of the Gault—the proofs of a drift of fine sediment from a great and not very distant land. Subsequent denudation has removed so much of the Chalk from the western and northwestern parts of England that we are mainly left to conjecture in any attempt to sketch the physical geography of this epoch. Outlying patches, indeed, occur even as far away as Antrim and the western isles of Scotland, but these are of no great thickness, and represent, as their fossils show, quite the upper part of the white chalk of England.‡ Probably all this country, with much of Wales and

* See p. 187.

† "Geology," part ii. ch. xx.

‡ In Antrim they are underlain by greensands, which seem to correspond with the Upper Greensand and some of the marly chalk of England, so that apparently a great gap exists in the record. In Scotland the beds directly below the Chalk indicate estuarine, perhaps almost fresh water, conditions.

Ireland, was wholly, or almost wholly, submerged. The great western land must have been broken up—probably for the first time—into scattered groups of islands, pierced by long fjords, and communications have been opened out between the Atlantic waters and the European sea. This was a most important epoch in the physical history of the British Isles; for by the time that it closed the western frontier of the old ocean barrier must have been profoundly modified, and all the lowland region was covered with a thick slab of white ooze, spread out like plaster from a mason's trowel.

Centuries on centuries must have passed while this mass—"thick and slab"—was slowly growing; centuries followed of which our own country has preserved no record. Between the topmost beds of the Cretaceous system and the bottommost of the Tertiary series in Britain an enormous interval of time must have elapsed—an interval long enough to make a complete change in the fauna, for hardly a single species has crossed the gulf between the older and the newer epochs. A fuller account of this change—perhaps in some respects the most remarkable in the geological record—must be left for another chapter; this must be restricted to the physical geography. Throughout the greater part of the Tertiary era the western and northwestern part of Britain appears to have been dry land. The Eocene and Oligocene deposits (for it is needless to separate them in a general description) attain a maximum thickness of some 2000 feet, and are variable in character. The chief subdivisions can best be noticed in passing. When first the record becomes legible, we see that a triangular area on either side of the present Thames was occupied by a shallow sea which extended eastward toward Northern France and Belgium. In this was deposited the light-colored quartz-sand called the Thanet Sand, a mass seldom so much as 60 feet in thickness. A study of the area occupied by this stratum leads to the conclusion that in the general elevation which closed the Cretaceous period the ground had risen in the region of the Weald of Kent and Sussex, and the surface here was a few hundred feet higher than it was further north. In the one place a low dome-like mound had formed, in the other a shallow trough. The axis of the elevation extended from west to east, indicative of a feature on the earth's crust which afterward assumes a greater importance. But after this crumple was formed the whole region east of a line extending roughly from the Wash to Torbay gradually sank down. The movement at first must have been extremely

slow, for the marine deposits of the Thanet Sand * are succeeded by the estuarine and fluviatile beds of the Woolwich and Reading group, which can be traced as far south as the Isle of Wight and as far west as Wiltshire. The great western river by which the sands and clays of the Weald were deposited again asserts itself, though much less conspicuously, for the total thickness of this Tertiary group is less than a hundred feet. Then the sea again rolled in as the land sank more rapidly. A shingle bed in the metropolitan area marks its advance, and forms a basement to the so-called London Clay. This stiff tenacious deposit can be traced from the valley of the Thames northward as far as Yarmouth, in Norfolk, southward to the Isle of Wight, and westward into Wiltshire. It is often from 300 to 400 feet thick; occasionally it exceeds 500 feet. All the southeast of England must have been submerged, but it is just possible that a low dome-like island may have risen above the central part of the present valley of the Weald. The London Clay, like those already described, is formed by the mud brought down by large rivers into the sea. In several places, especially in the island of Sheppey, the fruits of various tropical plants and logs of wood perforated by *Teredines* † are mingled with marine shells, which are sometimes abundant. The great western stream was probably the chief contributor to this deposit, but its extension northward to Yarmouth may indicate that the northeastern river, which has been already mentioned, resumed its course after the submergence in Cretaceous times. This, however, is "positively its last appearance" on the geological stage.

The group of deposits which succeeds the London Clay indicates more estuarine conditions. Sands, on the whole, dominate over clays, but the Bracklesham beds of Sussex, which can be traced, though in a more arenaceous form, over much of Hampshire and in the Isle of Wight, together with the Barton Clay—somewhat later in date—of the latter district, indicate that the downward movement was at times more rapid. Plant remains which occur at various horizons on the western part of the area indicate the inflow of at least one important river from that side.‡ Unfortunately the record soon breaks off on the north of the Thames, only a few

* The Thanet Sand can be traced northward as far as Suffolk.

† The *Teredo* is a mollusk, which still survives and makes burrows in piles and floating timber.

‡ It is now believed that the lacustrine deposits of Bovey Tracey, in Devonshire, belong to the Eocene, probably to the epoch succeeding the London Clay.

isolated patches of sand capping the London Clay, and indicating that, for a time at least, the sea extended for some distance beyond that valley. The great western river still contributed largely to the sediment, but as by this time much of Britain had become dry land, other important streams in all probability emptied themselves into this Anglo-Parisian sea, which never can have been at all deep. It

FIG. 137.—RESTORATION OF THE GEOGRAPHY OF BRITAIN IN LONDON CLAY TIMES. (*After Jukes-Browne.*)

Water and land as in Fig. 133.

may have presented a very rough resemblance to the Adriatic, but in which direction it communicated with the open ocean cannot be easily determined.

The area over which the geological record is preserved continues to diminish, and the deposits which formerly were assigned to the later Eocene, but now to the earlier part of the Oligocene, are almost restricted to the Isle of Wight.* Here they are mainly of

* The principal subdivisions are the Headon Beds, the Benbridge Beds (wholly fresh water), and the Hempstead Beds (estuarine and marine).

fresh-water origin, but estuarine conditions are indicated in the middle of the Headon Beds, and the record terminates with a marine clay, which points to a more rapid downward movement, leading to a recurrence of conditions resembling those under which the Barton Clay was deposited. During this period, as will be indicated in the next chapter, great changes were being made in the physical geography of Europe, which no doubt produced their effects in Britain.

After this the record for a considerable time is a blank. There is not a single deposit in all England which can be assigned to the Miocene period, as it is at present defined. This was an age of sculpturing, not of building—when the lowland districts were carved into hills and valleys, and the first outlines of their physical features were rudely blocked out. But while the struggle between land and sea, which has been sketched in the preceding paragraphs, was being waged over the southeastern half of England, the western side of the British Isles witnessed events of a more startling character. This region, as has been said, shared to some extent in the downward movement which characterized the Cretaceous period. The depression probably reached its maximum at the time when the record closed in England, and when the chalk of Antrim and Mull was deposited. The movements of the crust which replaced for a time deposition by denudation, and produced the gentle undulation of the Weald region,* seem to have disturbed the equilibrium of Nature more seriously in northwestern Britain, and resulted in a succession of volcanic outbursts, long in duration and terrible in intensity,† over a broad belt of country, extending at least from Carlingford, in Ireland, to the extreme north of Skye, on the west coast of Scotland. Eruption succeeded eruption, volcanic mountains were built up, in some places probably as high as Etna, and vast sheets of lava were ejected, which flowed away in streams from the cones, or welled up through fissures, till they covered some hundreds of square miles.

The rocks in many places are rent and riven with dykes. How far these extend to the eastward is difficult to determine, but it is almost certain that some of the dykes, even in northeastern England, must be referred to this age.‡ It was an age of fire, the like

* P. 386.

† These have been described by Professor Judd in a series of papers published in the *Quarterly Journal of the Geological Society*. The first appeared in 1874.

‡ Such as the Cleveland Dyke, in Yorkshire, which cuts through rocks ranging from the

of which had not been seen since the days of the Old Red Sandstone. It lasted long enough to eject huge masses of lava, ash, and agglomerate, which differed greatly in mineral characters, and before it closed sufficient time had elapsed to furrow the plateaus with deep valleys, down which the molten streams from the latest outbursts flowed. The Red Hills of Skye and the wild crags of the Cuchullin range have been sculptured out of the deep-seated masses from which the volcanic cones, now vanished, were supplied. Staffa, the

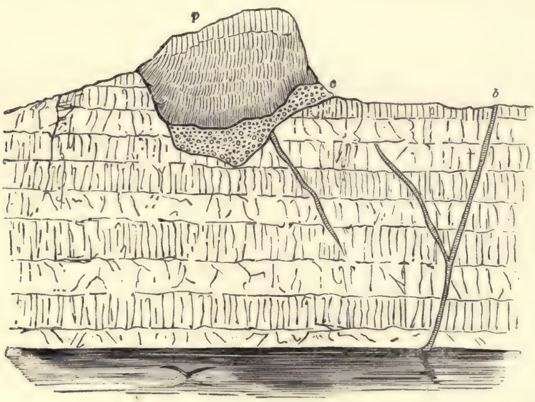


FIG. 138.—SECTION OF THE SCUIR OF EIGG (*Sir A. Geikie*).

(*b*) Dykes cutting through the plateau composed of lava flows and (*c*) old river gravel: (*p*) pitchstone of the Scuir.

Treshnish Islands, and the plateau of Antrim are fragments of the floods of basalt; all these attest not only the grandeur of the eruptions, but also the erosive force of wave and stream. Nowhere, however, is the lesson taught more impressively than in the island of Eigg. All who have traveled along the west coast of Scotland are familiar with the Scuir, that mighty wall of rock which crowns the steeply sloping ridge back of the island. It is a rendering in stone of the saying, "Every valley shall be exalted." Where the Scuir now rises, there, after the most violent outbursts had ended, a vast plateau, built up of flows of lava and occasional beds of volcanic

Carboniferous to the Jurassic, and ends near the sea, south of Whitby, after a course of 90 miles, according to the most recent estimate.

ash, stretched away on every side. It attained a thickness of not less than eleven hundred feet above the Jurassic deposits on which it rests. A long pause followed, during which rain and stream went on with their work, till they had excavated a valley at this place probably quite four hundred feet deep. Its bed was strewn with fragments, more or less water-worn, not only of basalt, but also of older rocks, which at present occur miles away to the north. Then a volcano broke out somewhere on the flank or in the bed of this valley. Its lava flows poured down the glen till this was filled by a mass of black glass, which differs greatly in chemical composition from the basalt forming the walls of the ravine. That done,

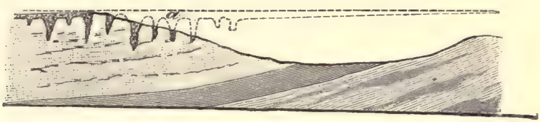


FIG. 139.—SECTION AT LENHAM (*J. Prestwich*).

Showing the present outline of the ground, the probable extension, originally, of the Pliocene deposit (*a*), and the chalk, etc., since removed by denudation.

denudation again set in, and rain and stream, wind and wave, converted the plateau into an island, and the valley into a fragment, until at last its sides were wholly carved away, and the lava stream which had flowed along its floor was left perched on high above the slopes, which lead down to the sea from the dry bed, where the gravel of the ancient river may still be found.*

Pliocene deposits cover only a comparatively limited area in Britain. Of these a small patch of clay, near St. Erth, in Cornwall, may prove to be the earliest representative, if, indeed, it may not claim admission into the Miocene; † but with this exception they are restricted to the eastern side of England. The older and thicker—though it does not exceed seventy feet—but, so far as is known, the most restricted in extent, is called the Coralline Crag. This is generally a yellowish, sandy, calcareous rock, rather friable,

* Some fossil wood (coniferous) has been found in the river gravel, but it does not determine the age very precisely. The island appears to have assumed pretty nearly its present form by the end of the Pliocene period. I am indebted to Sir A. Geikie, by whom the history of the Scuir has been worked out, and to the Council of the Geological Society for the diagram illustrating this description.—*Quarterly Journal*, vol. xxvii. 1871, p. 308.

† The discovery is but a few years old, and the examination of the fossils has not yet been completed.

which was probably deposited in a sea rather less than a hundred fathoms in depth. But, as a marked unconformity separates it from the overlying Red Crag, a considerable thickness may have been removed. The Red Crag is usually a ferruginous sand or gravel; it indicates a shallower sea, and more variable conditions of deposit, but it covers a much larger area than the other. At Lenham, on the North Downs, some pipes in the chalk contain sandy gravel which resembles the Red Crag in color, but the fossil evidence justifies the reference of it to the earlier period, when the depression of the land, as already said, was greater.

The Red Crag is succeeded by some clayey, sandy, and gravelly deposits, which in one case may represent a portion of it.* These practically bring the Pliocene period to a close, and indicate the approach of the marked climatal changes which ushered in the Pleistocene or post-Tertiary epoch. One of them suggests the conclusion that, when it was deposited, part of the bed of the North Sea had become dry land, and that a large river, possibly formed by the junction of the Rhine and the Thames, passed along the Norfolk coast, very near to the site of Cromer. We see, then, that in the course of the Miocene and Pliocene periods the direction of the drainage from the eastern side of England and the opposite parts of Europe was changed, so that the flow of water and the transference of sediment was no longer from north to south, but in the contrary direction. By the close of the Pliocene period the present physical geography of the British lowlands must have been sketched out, and the rivers must have occupied valleys which corresponded, on the whole, with those along which they are still flowing. Since then changes far from unimportant have occurred. Channels have been deepened, widened, in a few cases deserted and a new path adopted; but a map of England at the Cromer Forest Bed epoch, if drawn on a small scale, probably would not have differed very materially from one of the present day, except in the position of the coast line.

Bearing this fact in mind, we will endeavor to indicate as briefly as possible the main facts of the final chapter in the physical history of the British Islands. The subject is full of difficulties, and has borne an abundant crop of controversial writings. All geologists, however, are thus far in agreement: That during the later part of

* There are many difficulties as to the precise correlation of these deposits, the united thickness of which does not exceed a few yards; but on these we must not dwell.

the Pliocene period there was a marked, perhaps a rather rapid, fall of temperature,* not only in these islands, but also in a large part, if not the whole, of the northern hemisphere.† The more mountainous districts of Scotland, Ireland, Wales, and England were covered with snow and glaciers ; deposits are spread over a large part of the lowlands, which sometimes attain a thickness of from 100 to quite 200 feet, and are, directly or indirectly, the product of ice. These deposits consist partly of sand or gravel, partly, and more characteristically, of bowlder clay. This material is generally a stiff tenacious clay, the nature and color of which is rather variable, for at least a part of its materials has evidently been derived from older argillaceous strata, which come to the surface at no great distance. It contains many fragments of harder rocks, both rounded and angular, limestones of various sorts, chalk—pebbles of this being very common—flint, shales, including even such a perishable deposit as the Kimeridge clay, sandstones, and grits ; contributions, in short, from all kinds of Secondary and Primary rocks, with fragments of various crystalline rocks, such as granite, basalt, and schists. These last have come from Scotland, or possibly, in some cases, even from Norway. In a word, clay and fragments alike commonly testify to a drift of material in a direction roughly southward. Occasionally these fragments reach a huge size. On the coast of Norfolk, on either side of Cromer, masses of rock, measuring from fifteen to twenty yards in length, are fairly common, and they sometimes attain a much greater length, though, as a rule, they are not more than four or five yards thick. Most of these are chalk, and this apparently the chalk of the adjacent regions ; some, however, are gravel. These must have been frozen solid in order to travel. At Roslyn Hill pit, near Ely, a mass of chalk has been quarried away which was embedded in bowlder clay, and must have been full 400 yards in length. Both on the eastern and the western sides of England there appear to be an upper and a lower mass of bowlder clay, with more gravelly beds between, but the latest of these deposits is much more widely distributed than the earliest, which is commonly limited to the eastern and western coasts. This tripartite arrangement is by no means constant. We may, however, affirm that if in the inland districts only a clay

* The explanations offered of this change of climate will be mentioned in a later chapter.

† There is evidence of a similar epoch of cold in the southern hemisphere, but, as yet, it has not been proved that the two were simultaneous.

occurs, it belongs to the upper division; and that when both this and gravel are found in connection, the latter is generally the lower of the two.

What, then, is the history of this singular group of deposits? Here geologists are at issue, differing chiefly in their views as to the origin of the bowlder clay. One party regards it as the direct product of land ice, the *moraine profonde* of an ice sheet; the other, as composite and more variable in origin, and though due indirectly to the action of ice, as deposited for the most part under water. Thus the one maintains that during the Glacial epoch the land stood at a rather higher level than at present, the other that it was generally lower, and that the depression at one time was very considerable. They would not, however, deny that when the temperature was most severe Scotland must have resembled the southern part of Greenland; that Snowdon and Helvellyn were the centers of glacier systems which filled every valley in the surrounding mountain regions and came down to the sea; that even the Pennine Hills and minor groups, like those of Charnwood Forest, may have had their permanent snowfields; but these geologists hesitate to bury almost all Britain beneath an ice sheet which extended as far south as the northern border of the valley of the Thames.* One school of modern glacialists has not shrunk from enveloping the Arctic regions with one vast ice cap which swept in its slow and unresisted march over these islands, and from drowning a large part of North Central Europe in the waters of a huge lake, formed of the rivers ponded back by the margin of this gigantic ice sheet. That, however, may be regarded as the view of extremists. A much larger and more moderate school supposes that the ice sheets originated in the various mountain groups which extend along the northwestern margin of the continent of Europe—Scandinavia, Scotland, the North of Ireland, the Lake District, and Wales, each forming an independent center of supply, but contributing to a common sheet of ice, the southern margin of which possibly extended as far south as the "northern heights" of London. By these geologists the bowlder clay is regarded as a land deposit; the intercalated sands and gravels, as formed by streams, or in lakes produced by the ice locally

* True bowlder clay is found about Finchley, Muswell Hill, Hendon, on the higher ground, but after that is not seen again till the coast of Sussex (near Pagham and Selsea), and this deposit is universally admitted to be quite distinct. The erratics indicate a drift from the west and south. (See Clement Reid, *Quarterly Journal of the Geological Society*, 1892, p. 344.)

obstructing the course of rivers, and as indicating a temporary amelioration of the severest climate. A third school, however, maintains that during the Glacial epoch the land, generally, over the British Islands, at first slowly sank and then as slowly rose ; that its level at the outset in all probability was somewhat higher than at present, but that afterward there was a steady depression, more marked on the western than on the eastern side of Britain, since it amounted on the former to some 1300 feet, possibly even to more than 2000, but on the latter to less than half this amount. By these geologists the bowlder clays are considered to have been deposited in the shallower water during the earlier and later part of the epoch, when the sea was full of floating ice, the greater portion of this being, not bergs from huge glaciers, but coast ice, which had formed on the shores of a sea studded with islands. According to this view the bowlder clays, which occur at various heights, frequently up to about 400 feet above the present level of the sea,* and occasionally up to more than twice that elevation, represent conditions such as now exist in many parts of Baffin Bay, while the sands and gravel indicate that the sea was then more free from ice, and its depth generally was greater.

The space at our disposal does not permit of anything more than a mention of the chief arguments on which the controversy turns. The last-named school urges the difficulties which are involved in attributing to the action of land ice a deposit like the bowlder clay which is found on the plateau of Suffolk, sometimes 80 or 100 feet thick, at a height of full 300 feet above the sea, and in the valley of the Cam certainly not less thick, with its base occasionally slightly below the present Ordnance datum line. Such an uphill and downdale movement in an ice sheet which must have originated on ground comparatively low seems to them incredible, and they point to the occurrence of marine shells, occasionally in the bowlder clay, and not unfrequently in the sands and gravels, as proofs of a submergence. Most of the arguments on both sides are of a rather indirect character; the last one, however, is more direct; the frequent occurrence of marine shells in a deposit anterior to the age of man is generally held to be an indication that the locality has been under the sea. It was the line of reasoning adopted in the opening pages of this book. The *onus probandi* is accordingly thrown upon

* This statement applies more strictly to the bowlder clays belonging to the later part of the epoch ; that representing the earlier—the Till—does not extend above some 200 feet.

those who make the contrary assertion, and they meet the argument by the following hypothesis: The ice sheet in passing over the bed of the Irish Channel or of the North Sea is supposed to have plowed up masses of shelly gravel, and to have transported them therefrom, often with their fragile contents uninjured, to the spot on which they are now found. The hypothesis is ingenious; but many geologists, including the present writer, question almost every assumption on which it is founded, and are unable to understand how a glacier could possibly transport shells over very irregular ground and deposit them in well-stratified gravels on such places as Moel Tryfan * (which at that time ought to have been covered by

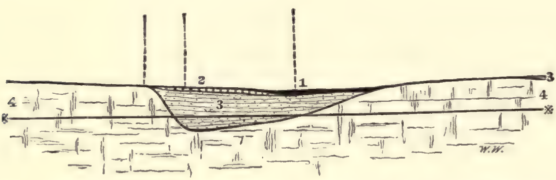


FIG. 140.—SECTION OF BURIED RIVER CHANNEL IN ESSEX (*W. Whitaker*).
(1) Alluvium and river gravel; (2) old river gravel; (3) Glacial drift; (4) chalk.

ice) or Gloppa, near Oswestry, where numerous shells have been found belonging to over sixty species, many of them uninjured.†

The ice gradually melted away, the climate slowly improved. The rivers, where the land had been buried either beneath glaciers or beneath the sea, began to clear away the masses of incoherent *débris* by which in many places their paths had been obstructed. The present valley systems, as already remarked, were mapped out in preglacial times, but since then they have undergone minor changes, by no means inconsiderable. It can be proved that many of the greater rivers formerly flowed along channels which followed slightly different lines from their present courses, and were at a lower level. Even among the undulating uplands of Essex the channel of an ancient tributary of the Cam has been detected, now

* It is about 1330 feet above sea level, down to which glaciers certainly came in North Wales. Here, then, the invasion of North Sea glaciers would have been prevented. Moreover, it is about five miles from the sea, and unless the ice came from the west, or the shells were picked up at the mouth of the Menai Straits, it must also have crossed Anglesey.

† The place is about 1100 feet above the sea and more than thirty miles from it.

buried beneath bowlder clay;* but while in some cases the streams seem to have done little more than clear away *débris* and "return to ancient ways," in others there is evidence of no inconsiderable amount of erosion. Patched about at various elevations in the more lowland regions are beds of gravel, often rather coarse, and generally indicative of the action of streams larger and stronger than the present rivers. When glaciers still lingered in the mountain valleys, and the upland districts in winter time were swathed in snow, the rivers would run for part of the year as strongly as

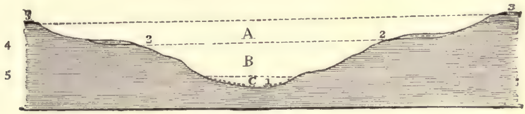


FIG. 141.—SECTION OF THAMES VALLEY AT GORING (*J. Prestwich*).

(1) Postglacial drift; (2) Glacial drift; (3) preglacial gravel; (4) Lower Tertiary strata; (5) chalk.
A. Denudation during the early Glacial period, about 160 feet.
B. Denudation during the later Glacial period, about 220 feet.
C. Denudation during the postglacial period, about 70 feet.

they now do only in very exceptional floods. Some of these gravels on the higher plateaus may be preglacial; some also which lie to the south of the Thames may be contemporary with the bowlder clay to the north of that river; but others, like the "plateau gravels" of East Anglia, are certainly postglacial. The highest of these seem to have little connection with the existing river systems—indeed, they may be a marine deposit—but as they occur nearer and nearer to the present sea level they become more and more closely connected with the streams. The valley of the Medway, as already mentioned,† has been deepened by 250 feet in postglacial times, that of the Thames at Goring, according to Professor Prestwich, during the later glacial and postglacial epoch, by about 290 feet;‡ and evidence exists in many places that rivers have added, in times

* The bottom is rather below the Ordnance datum line, and the drift by which it is filled is in places 218 feet deep.—W. Whitaker, *Quarterly Journal of the Geological Society*, xlvi. p. 337. The diagram on p. 396 is from this paper.

† See p. 115. The breadth of the valley at this part is seven miles.—*Quarterly Journal of the Geological Society*, xxxi. p. 465.

‡ The amount of change in the valley of the Lower Thames is a matter of some dispute, but as bowlder clay overlies gravel at Totteridge, and the same gravel can be traced by Finchley to Hendon, where it is rather less than 250 feet above Ordnance datum, there must have been a difference of level in preglacial times of nearly 200 feet, and the valley of the Brent and of the Thames must have been at least sketched out.

certainly postglacial, not much less than 100 feet to the depth of their valleys.

Even the last pages of the story of our planet indicate that whether or not a great submergence affected these islands during the Glacial epoch,* movements, both upward and downward, have subsequently occurred. These may be noticed in passing, as we sketch, in as few words as possible, the last stages of the development of the British Isles.

The bolder hill regions, of which remnants can still be found, as already said, were all in existence when the Secondary era began. Hence the excavation of their valley systems must have commenced long before it came to an end. Great changes, no doubt, were made during Tertiary times, but to escape from a groove is no easy matter; hence, unless a submergence had been very prolonged, and the deposit of material very great, a river, when the land was once more elevated, would almost certainly return to its former channel. Thus these ancient valleys would produce an effect upon the lowlands by determining the points where the chief sculpturing tools were applied, so that as the ground continued to rise the highland valleys would be prolonged seaward through the newly exposed sediment. Since the sea during Eocene times appears to have extended over at least the southeastern half of England, it might have been expected that the rivers would have flowed in that direction, so as to discharge the drainage of the greater part of England into the sea north or south of the Straits of Dover. But, as a glance at a map shows, the courses of the four most important rivers are by no means so simple. The Thames, indeed, takes the direction which might have been expected, but it rises in Gloucestershire, not in Wales, and is altogether a lowland river. The Dee and the Severn rise far back in Wales, and when they issue from the hill region—not very far apart—the one turns northward toward the Irish Sea, the other southward toward the Bristol Channel, and the course of each is almost a semicircle. The comparatively low central plateau to the northeast of Edgehill, in Warwickshire, parts the drainage of the Wash and the Thames, and separates both from that of the Severn, thus occupying a most important position in the physical geography of England. Again, a line running irregularly from east

* A considerable depression, amounting to perhaps 500 feet, would be admitted for Britain by all but a few very "ardent glacialists." It seems impossible to deny that the submergence at Montreal, in Canada, amounted to at least 520 feet, and there is evidence elsewhere, as already stated, of a yet greater depression.

to west through the southern counties forms a watershed right away from the Straits of Dover to Devonshire. The parting of the Thames and the Wash drainage in the east-central districts possibly may be related to the same feature. How, then, are these

FIG. 142.—MAP ILLUSTRATING HOW A RISE OF 600 FEET (100 FATHOMS) WOULD UNITE GREAT BRITAIN WITH IRELAND AND THE BRITISH ISLANDS WITH THE CONTINENT.

anomalies to be explained? In connection with this a further question may be asked—What account can be given of the Bristol and St. George's channels?—for they bear a very close resemblance to submerged river valleys. This is the change which an elevation of 600 feet would work in the latter: The water would retreat, and Ireland in reality form part of the United Kingdom. A broad plateau, generally 300 to 400 feet above sea level, would link Donegal

with Islay, Mull, and the Scotch mainland. This would slope down, quickly on the southern side, to a rather wide valley, extending between Ireland on one side and England and Wales on the other. The floor of this (assuming the present level unchanged) would descend but slightly till it had come a little south of Cardigan Bay, when it would fall below the 300-foot contour line, and then shelve slowly seaward. It is difficult to understand how such a valley could be primarily formed except by the action of rain and rivers, though in such case we must assume its slope once to have been more rapid than it is at present, for this, on the average, is less than three inches to a mile, and so is more favorable to deposition than to denudation. Irregularities also exist in the floor, which must be due either to an irregular deposition of materials on it or to unequal movements in it, and the latter supposition appears to be the more probable. As the "valley of the Irish Sea" is on a far larger scale than that of the Dee, or even of the Severn, it may have been begun at a somewhat earlier date, as in Eocene times, while the sea still covered the greater part of England, and the drainage of Eastern Wales meandered slowly toward it over a strip of lowland.

Two causes may have co-operated in producing this anomalous direction of our river systems, and in preventing the restoration of the western continental land, after the Cretaceous or even the Eocene submergence. The first: That, as already mentioned, the western border of Britain was the scene of great volcanic eruptions, which began soon after the Cretaceous period and continued probably into the Miocene. These, as already explained,* might prevent any upward movement, and even produce subsidence. The second cause is this: Shortly before Eocene times the elevation of a considerable tract of land, on the site of the present Weald of Kent and Sussex, had begun, and movement in an upward direction doubtless continued over an elongated area, at least 300 miles in length, until comparatively late in the Tertiary era. The system of flexures, of which this formed a part, very possibly affected, during post-Eocene times, a large portion of the eastern half of England; so that on its western side the land was made to shelve in that direction, and the Severn and the Dee were forced to flow parallel with the borders of Wales until, after rounding the hill region, they ran down the lowland slopes in a western direction.

* P. 247.

The Trent, as its sources lay further north, may have just succeeded in turning the southern extremity of the Pennine Hills, and may have been forced afterward into a northern course by the effects of some minor flexure. It has been suggested * that this river originally passed out seaward through the gorge in the Lincolnshire Wolds which is now occupied by the Witham, and that the separation of the two rivers and the diversion of the former into the Humber may be an event later than the Glacial epoch.

Whatever may have been the conditions under which the bowlder clays were formed, it is almost certain that during the deepening of the river channels, and the formation of the coarse gravel beds mentioned above, the land stood at a level higher than at present. Ireland, for a time at least, was linked to Scotland; England, for long, was united to France. The latter effect would be secured by a rise of 150 feet. Double that amount would much more than suffice for the former. But the area of England would be considerably enlarged even by the smaller elevation, for it would convert into dry land much of the Bristol and St. George's channels and of the North and Irish seas. For instance, it is almost certain that at this time a continuous ridge of chalk extended from the north of Swanage right across to the Isle of Wight, from which ridge a river flowed eastward along the valley of the Solent. From this it follows that the coast line of Britain has been deeply indented and sculptured, largely by the sea, even in this last geological epoch. Where the rocks are hard, as on the western side, there probably the work has been in process at least since the period of the Cretaceous submergence; but the shaping of the Isle of Wight and the severance of England and France must be events, geologically speaking, very recent.

In many places round our coasts, but more especially on the south and west, the remains of trees, still rooted in the earth, can be detected for some distance below the level of high water. They are proofs of a subsidence,† but this may not have been great, for the utmost change need not have exceeded 50 feet. Another group of facts, however, points in the contrary direction. In many places on the coast of the British Isles raised beaches, as already

* By A. J. Jukes-Browne, *Quarterly Journal of the Geological Society*, xxxix. p. 606.

† Some geologists are of opinion that these submarine forests may be explained by the removal of underlying sandy beds through the action of springs; but the present writer thinks that, though this may have produced some local effect, the explanation is insufficient to account for all the phenomena.

stated, are found. They occur at different elevations, and must be referred, of course, to different dates; and even the same beach, as it is traced along, does not maintain a uniform height; but the latest, which is frequently from 20 to 30 feet above sea level,* indicates an old depression which is undoubtedly later in date than some, probably all, of these forests. On this point, however, it is difficult to arrive at any very precise conclusion, for the evidence bearing

FIG. 143.—THE NORTH DOWNS AND WEALD VALLEY.

on it is conflicting and confused. The raised beaches as a whole are postglacial, and indicate in the western parts of Scotland a former considerable submergence. They are found not seldom up to a height of about 350 feet, and may be traced still higher, perhaps to some 1100 feet.† These, however, possibly belong rather to the later part of the Ice Age, when the glaciers were rapidly dwindling; but the lower beaches must be much newer than the coarse river gravels, for in the former tools of polished stone, and even canoes, have been found. These show that Britain must have been inhabited by races far more civilized than those which abode in it immediately after the Glacial epoch. Moreover, the fjords of Norway, the lochs of Scotland and Ireland, the estuaries of Wales and Western England generally, all indicate submerged valleys, and prove that the latest upward movement has not entirely compensated for a preceding one in the contrary direction. This submergence probably enabled the waves to replace the isthmus between Kent and the Boulonnais by a strait, and to trespass rapidly on the

* It is sometimes called the "twenty-five-foot beach," as that is often its height.

† The author considers the Parallel Roads of Glenroy to be raised beaches.

southern and eastern coasts of this country. Possibly stories of submerged districts, such as the "lost land of Lyonesse," may be in reality vague traditions of primeval days, before Britain was an island or Rome had been founded. Certain it is that, as already shown, the process of change has continued into historic times.

When the history of the "building of the British Isles" begins, their site appears to be on the border of land and of sea—the one, stretching far away to the west, part of a semi-continental mass which extended at least from the seventieth to the forty-seventh parallel; the other, part of a very large island-studded sea which covered much of Western and Central Europe. The history ends as an island group, built up of geological fragments of almost every age, with a great ocean deepening to the west and a large continent for its immediate neighbor on the east.

> The hills are shadows, and they flow
> From form to form, and nothing stands.

CHAPTER V.

THE BUILDING OF EUROPE AND OTHER CONTINENTS.

IN the preceding chapter "the building of the British Isles" has been traced at some length. This has been done because not only are the localities likely to be familiar to most readers, but also a fairly minute description of any one region may indicate the nature of the process in other parts of the globe. But the latter must be noticed much more briefly. In their case the difficulties of the task are far greater, for information concerning them, except as regards Europe, is often either very fragmentary or altogether wanting. Of this continent we purpose to give a succinct description, especially of those parts which are more closely related to the British Isles, and to conclude with a slight sketch * of the geological history of other quarters of the globe.

In regard to Europe time will be saved, perhaps also our account will be rendered more intelligible, by reversing the order of treatment followed in the case of the British Isles, and working from the present physiography to the past geology. On examining a map of Europe, whereon the contours are clearly indicated, we observe that it exhibits four distinct types of surface—plains, uplands, highlands, mountain ranges. Three of these are represented in Britain, though on a restricted scale as regards area: the plains, by the fenlands on many of our river valleys; the uplands, by the ordinary undulating regions, such as the chalk hills of Wiltshire or the limestone districts of Somersetshire and Gloucestershire; and the highlands, by the northern part of Scotland. Obviously the classification is a rough one, for a hard and fast division is not possible. But the fourth type—the mountain range—strictly speaking, is not represented in Britain. Of it the Pyrenees, the Alps, and even the Apennines and the ranges east of the Adriatic, are examples. These seem to be in some way connected with the Mediterranean Sea and

* In writing this sketch I have made great use of Professor Kayser's "Text-book of Comparative Geology" (translated and edited by Mr. P. Lake), and consulted with much advantage Sir A. Geikie's "Text-book of Geology" and Professor Prestwich's "Geology," vol. ii., which contains an admirable geological map of Europe.

its associated basins, while the highland type belongs to the regions which are more nearly related to the Atlantic and Arctic oceans. On examining a geological map we find the distinction between these two types to be connected with a difference in age. The mountain ranges are comparatively modern in date: the highland regions have existed from an antiquity much more remote. In their day they also may have been mountain ranges; but time has told upon them, and they are now like the carious stumps of mountain teeth.* Hence, as we go back in geological history, the grandest and most salient features in the scenery of Europe are among the first to disappear, and comparatively inconspicuous highland districts prove to be much more permanent landmarks. These form the "horsts" (p. 218) round which several of the later geological formations successively crop out in almost concentric zones, while the former are like sharp "plaits" or "puckers" of the crust which sometimes suddenly interrupt a surface comparatively level. The Pyrenees, the Alps with their southern offshoots, the Carpathians, and the Caucasus are comparatively modern; but the Cevennes with Auvergne, the Vosges, the Black Forest, and the linked group of highland masses which covers so much of Central Germany, as far as the "Wald" of Bavaria and Bohemia, besides a considerable part of the Spanish peninsula, are very old, and from time to time have played an important part in the physical history of Europe.†

We have already spoken of the close connection between England and France. The chalk hills which flank the valley of the Somme recall those south of the estuary of the Thames. The sandstones near Boulogne have much in common with those on the coast of Kent. Differences may exist here and there; but the relationship, as will be seen presently, extends still further. Belgium and Holland, with a little of the northern part of France, and all the North German lowland, are largely covered by drifts which are closely allied to the Glacial and postglacial deposits of England. Some geologists believe that the Scandinavian ice sheets once trespassed further south than Berlin; others refer the drifts of this region to a more varied origin, and regard them as mainly subaqueous. The same

* This, in regard to Scotland, has been brought out with great force in an article by Professor J. Geikie in the *Scottish Geographical Magazine* (vol. ii. p. 145), and it is no less true of Western Scandinavia. The Ardennes are probably part of an old mountain range, and some Belgian geologists have asserted that it once rose to a height of 12,000 feet, or even more.

† Volcanic mountains are not included in these remarks.

remark applies to the Russian lowland, south and east of the Gulf of Finland. There can be no doubt, however, that in the Glacial epoch the ice sheet of Scandinavia extended considerably beyond the present coast line, and the glaciers which radiated from the Pyrenees and, still more, from the Alps, came down to within a few hundred feet of the sea level.* Those from the latter chain have left huge moraines on the plains of Piedmont and Lombardy, and the old glacier of the Rhone extended to within a few miles of Lyons.

In Pliocene ages a large part of Europe was a level surface, and the dominant features of its scenery did not materially differ from the present, though, doubtless, peaks and ravines, hills and valleys were then less completely sculptured than they are now. The North Sea occupied a large area, covering not only the east of England, but also Belgium and the adjacent part of northern France; and in the south the Mediterranean Sea extended considerably beyond its present limits; for, on the northern side, the lower lands of Italy, Spain, and Greece were submerged. Fluviatile and terrestrial deposits of the same period also occur both in these countries and in many parts of Germany and Austria, while Western Slavonia contains deposits more distinctly lacustrine in origin. The volcanoes of Italy and even the huge mass of Etna did not begin their existence till late in Pliocene times.

In the Miocene period, though a considerable part of Europe still remained dry land, the areas covered by sea were conspicuously augmented. But toward its end some very important changes occurred in the physical geography of the central region. Disturbances affected the chain of the Alps, which produced, as will be presently described, the most marked effects in the middle portion of the northern face. The Pyrenees and Carpathians were similarly affected, though not to a like extent. The English and North French areas were above water; but parts of Belgium and Holland, with Holstein and Friesland, were occupied by a sea, and marine deposits occur in the basin of Mayence. Gulfs from the Atlantic extended into the lowland districts of the Loire and the Garonne, and overspread much of the coast regions of Spain and Portugal. "From the Mediterranean, which still covered large areas in the northwest of Africa, the Miocene sea extended through the Rhone valley to the level part of Switzerland, and thence through Upper

* See p. 135.

Swabia and Upper Bavaria to Vienna. An arm of the sea stretched north of the Carpathians to Moravia, probably even to Galicia, while a second formed the connection with the great 'Pannonian basin,' which extended over Hungary and a part of Steiermark, Carniola, Croatia, and Bosnia, and reached east beyond the present Black and Caspian seas, which are only the last remains of that great Miocene ocean. The Alps, like the Carpathians, were still islands in the Mediterranean, while the greater part of Sicily, Malta, etc.—islands formed chiefly of marine Miocene beds—was at that time under the sea." * The Mediterranean, however, appears to have been already separated from the Indian Ocean, for no marine beds of Miocene age occur in Egypt, Syria, Asia Minor, Persia, or Arabia. In Europe deposits of fresh water origin also are not unfrequent, and they alternate in the zone north of the Alps with the marine beds already mentioned. The volcanoes of the Eifel, the Rhine district, and the parts of Germany east of the Rhine, in Bavaria, Silesia, and around Schemnitz in Hungary, in Catalonia, and some of those in Auvergne, were in action during Miocene times.

The great earth movements which, as mentioned above, affected the newer mountain systems at the close of the Miocene period, must have finally determined the present physical structure of Europe. As the highland regions of Central France and Germany were already in existence, many of the river valleys which radiate from them may have been already defined ; but with a sea on the site of Mayence and fringing the north face of the Alps it is obvious that the greater part of the courses of the Rhone, the Rhine, and the Danube cannot yet have been determined, and the same is true of the lowland portion of the Po. Since the sea must have intercepted all the affluents of these rivers, as they emerged from the mountain regions, a date earlier than the beginning of the Pliocene period cannot be assigned to any part of their valleys which is clear of the Alps.†

* "Text-book of Comparative Geology," p. 353.

† The late Sir A. Ramsay maintained, and his reasons appear weighty (*Quart. Jour. Geol. Soc.*, vol. xxx. 1874, p. 81), that the Rhine, in taking its present course through Germany, occupied the valley of a river which in Miocene times flowed southward from the Hundsrück Taunus, this reversal of the direction of drainage being connected with a general northward tilt of that part of Europe, due to the last elevation of the Alpine region. The old valley being, to a great extent, filled up by Miocene deposits, the new stream would soon find a way out northward, and gradually excavate the present gorge between Bingen and Bonn ; so this noted feature in the scenery of Germany has been sculptured since the beginning of Pliocene times.

In the Oligocene period a sea appears to have spread itself inland from the shores of the Baltic and the North Sea over the lower ground of Germany to Leipzig, Cassel, and even Frankfort-on-the-Oder, and westward to the southeast of England, over Northern France and all around Paris, even to beyond the Loire. In the last two districts, however, and in Belgium, the marine are mingled with fresh water beds. Much of Southern Europe also was covered by sea, in which the rising Alps and the old highland regions of France and Germany probably formed islands, and the two areas of salt water may have been connected, at any rate at the time of deepest submergence, by a strait running from Frankfort to Cassel. In many places in the region which was generally occupied by the southern sea fresh water deposits are intercalated with the marine, especially in the vicinity of the Alps; in others the latter are wholly wanting. Among the highlands of Auvergne, for instance, was more than one lake * on the shores of which the volcanoes were in eruption from this time till a comparatively late epoch; streams of lava flowed over the newly formed fresh water beds, the latter sometimes reaching a thickness of 1500 feet. Similar deposits also are found in Provence and other parts of Southern France. The torrential rivers, which were furrowing the newly risen Alps, discharged huge masses of coarse gravel upon the marginal lowland, especially to the north of the central region, and in almost every direction covered a considerable area with finer sandstones and occasional marls. By the last set of movements these Oligocene gravels were raised to a height of some 6000 feet above the sea, as may be seen in the cliffs of the Rigi and the Speer.†

In Eocene times the Alps, Pyrenees, Carpathians, and Caucasus had no existence as mountain chains; but we will defer the important question of their development until the general structure of the continent at this period has been noticed. During a considerable part of it much of Europe was covered by sea. A large land area, indeed, very probably occupied the northern region, including not a little of Russia, and extending thence westward by Scandinavia on to Britain; but this was bounded by a sea on the south, which apparently covered part of North Germany, Denmark, Belgium,

* The largest, which covered the site of Clermont Ferrand, was some twenty miles wide and more than ninety long.

† The pebble beds go by the name of *nagelfluh* (nail rock); the sandstones are called *morasse*. The group, for the most part, is of fresh water origin, and a lake may have extended then over a considerable part of Northern Switzerland.

Northern France, and Southeastern England. Beyond this, in the same direction, lay land or a closely connected group of islands, and then came a sea which occupied "the whole of South Europe" and the present Mediterranean area, whence it extended southward far into Africa, and eastward right across Asia to join the Pacific Ocean. Here and there, however, it was interrupted by islands, now incorporated into the Alps, Carpathians, Pyrenees, and Apennines. In this wide expanse of ocean almost all traces of the present physical geography of Europe may be said to be lost; for since Eocene

FIG. 144.—BASALTIC PLATEAUS OF THE COIRON IN THE ARDÈCHE.
Here the underlying beds are Jurassic, but the lacustrine have the same effect.

times all the more sharply defined mountain systems of the southern half of Europe have virtually come into existence.

A brief sketch of the history of the Alps may serve to indicate a process which is repeated in many regions of the earth. During the greater part of the Secondary era the sea flowed where the Alps now rise; the vast masses of limestones, or of shaly and gritty mudstones, which more especially form the outer zones of these mountains, were in course of accumulation. The irregular floor on which they were deposited consisted mainly of very ancient crystalline rocks, with which locally some Primary deposits were associated—these, however, for the moment may be passed over. In places parts of this floor may have risen in islands above the sea level; but this can-

not be proved, and the evidence, so far as it goes, is unfavorable to the idea. Disturbances appear to have been first felt in the extreme east of the Alpine region, and the ground there may have emerged from the sea rather before the end of the Secondary era; but, as a whole, the Alps were not until the end of the Eocene. Along the northern zone, and, to some extent, on the southern also, a very thick shaly or sandy deposit, called the Flysch,* may be traced, which seems to indicate a westward traveling of similar physical conditions; for in the one locality it begins in Cretaceous times, and in the other, starting later, it concludes early in the Oligocene. All the beds, up to the age of the later Eocene strata of Britain, are affected by the great processes of folding which made the Alps. The first of these produced a mountain chain, probably not less elevated than the present one, the structure of which may have resembled that of the Eastern Tyrol, viz., a chain composed of three ranges, of which the central was the most strongly marked and formed the watershed. In speaking of the formation of a mountain chain taking place at a certain epoch we do not mean to imply that the event was sudden, as man counts time. Probably the area began to move much before, and continued to move long afterward; but it appears as if there were occasional epochs when the changes were more rapid, and these conveniently may be taken as dates. From early in the Oligocene to the end of the Miocene denudation in the mountain regions and deposition on its marginal zones progressed *pari passu*, until another period of intense movement began, which seems to have affected mainly the Central and Western Alps. As a consequence, probably, of this, a marked change may be observed in the orography of the Alps. East of the upper valley of the Inn the central range forms the watershed; but that river, with the Rhine, the Reuss, and the Rhone, appears to start from the northern face of the southern range, which continues to be the watershed until the Alps are lost in the Apennines. Simultaneously, however, with this change the northern range becomes orographically of greater importance, and it is flanked in Switzerland by an outer zone, including the Rigi and the Speer, which, as already mentioned, cannot be much earlier in date than the end of the Miocene period. In the Bernese Oberland—the grandest part of the northern range—the most extraordinary contortions may be observed, ridges of the

* In places this deposit contains some erratic blocks, remarkable both for quantity and for their occasional size.

older rocks in many places being bent over, or even thrust forward above masses of later date. This set of disturbances appears to have affected the whole region—at least as far as Dauphiné. The *massif* of the Pelvoux and Écrins, the ridges of the Grandes Rousses and Belledonne, occupy positions similar to that of the Bernese Oberland, and both ranges appear to be connected with and to culminate in the chain of Mont Blanc. Throughout this region, with one exception, the drainage is discharged northward or westward, all the rivers ultimately reaching the Rhine or the Rhone, chiefly the latter. The only water that finds its way to Italy is from the southern side of Mont Blanc; perhaps the exceptional elevation of this *massif* may have had the result of enlarging the area drained by the Dora Baltea, and thus changing for a short space the position of the watershed of Europe. When first the valley of the Upper Rhone was sketched out, the northern range very probably resembled that which forms the frontier of the Tyrol and of Bavaria, and had been already gashed by the river, which, if the ground rose gradually, would still be able to saw for itself a passage, so that the main outlines of the physical geography of the region would not be disturbed.*

The history both of the Apennines, on one side of the Adriatic, and of the mountains of Istria, Dalmatia, and Montenegro on the other, cannot be separated from that of the Alps. In them also indications of a shallowing sea are given by the Eocene deposits; the elevation into mountain ranges or chains is approximately contemporaneous with the movements of the Alps. The Pyrenees, though less complicated than the latter, appear to have a like history. There are similar marginal conglomerates, probably about the same age as the Swiss *nagelfluh*, and evidence may be obtained of not less than two movements, of which the first was the more important. The genesis of the Carpathians and of the Caucasus was probably connected with the same series of earth movements. In all these cases insular tracts of land may have previously risen above the water, or even mountains have occupied part of the site in ages long remote; but the chains did not begin to exist, as they are at present developed, until the end of Eocene times.

In the more northern part of Europe the interval between the Tertiary and Secondary eras appears to have been occupied by denudation rather than by deposition, though at Faxoe, Maestricht,

* This subject and other points in the history of the Alps are discussed by the author in three lectures, published in the *Alpine Journal*, vol. xiv. pp. 39, 105, 221.

and Meudon, near Paris, beds are found which help somewhat in bridging the vast gap, which in most parts of this region exists, between the top of the Chalk and the bottom of the Eocene. Here, on the whole, a larger area was occupied by sea in the Cretaceous than in the Eocene period, and the evidence suggests that first a steady rise, and then a less marked fall, affected a very considerable extent of country. But even so far back as this time we find some hint of a division of the waters along the line of the German highlands, and the great southern ocean seems to have held its ground continuously from the Secondary to the Tertiary era, but to have become, on the whole, more shallow during the latter.

During the Cretaceous period an ocean, studded here and there with islands, occupied the place of Europe. White chalk, identical with that of England, extends eastward for a long distance north of the line joining Brittany with the Ardennes. Probably the deposit once covered the whole area to beyond the Baltic, and stretched southward from the 55th parallel of latitude to the last-named regions and the German highland; for sands partly replace it at Aix-la-Chapelle, and coarse sandstones in the Saxon Switzerland. The sea also overflowed the southern half of Russia, and a large part of the countries bordering the present Mediterranean, beyond which it extended eastward into Asia, and southward into Africa. True chalk, however, was only formed in one or two areas of Central and Southern Russia. Limestones, indeed, are frequent, but those of Gascony and Provence, of the Eastern Alps, and the mountains on each side of the Adriatic are pure, but hard, furnishing very fine building stone, the fossils indicating different conditions and a partial separation from the northern seas. In the Central and Western Alps the limestones are often less clean, or replaced by other sediments. Probably they were formed in comparatively shallow water, and here and there actual fluviatile deposits occur, as in Provence and Carinthia, Istria and Dalmatia, and the Bakony. But there can be little doubt that during the Cretaceous period the European area, as a whole, was depressed more widely and extensively than even in the Eocene, or than in any other part of the Secondary era.

The Neocomian period in Europe, as in England, indicates more varied conditions, and a gradually progressing downward movement. The English fresh-water Weald finds a counterpart in Northern Germany;* the two may have been connected, but the German

* In Hanover, Brunswick, the Teutoburger Wald, etc.

Weald almost certainly must have been deposited by a different group of rivers. Probably they flowed from the mountain region of which Scandinavia is a fragment. In Spain also a similar group of rocks has been found, but in the area north of the present Mediterranean—the Jura and the Alps—marine beds are well developed, including limestones, which sometimes are very thick and pure.

In the Jurassic period the sea in Europe occupied an area similar to, but more restricted than, that which is concealed in the Cretaceous; indeed, the bolder physical features of the entire region appear to have remained unchanged throughout almost the whole of the Secondary era, the differences being mainly due to the greater or less extent of submergence. The English gulf was only a prolongation of the French sea, and in a southeasterly direction the sedimentary members of the system attenuate and the calcareous increase. The Lias, however, of North Germany and of the Alps is not unlike that of England, though in the more eastern part of the second region it passes into massive limestones, and indicates a greater distance from any important tract of land. Jurassic deposits cover much of Northern Russia, and may once have extended over most of the country, but were, perhaps, interrupted by islands in the south and in the adjoining part of Roumania and Hungary.

The Triassic deposits express, in a more accentuated form, a distinction, of which some trace remains, even in the Jurassic period, for the Franco-German Trias differs widely from that of the Alpine region. The former is closely related to that of England; the deposits, indeed, in Normandy clearly indicate the existence of similar conditions. When they reappear on the eastern side of France, both the Bunter and the Keuper present a general resemblance to the contemporaneous deposits in Britain, but here, as, for instance, in Alsace-Lorraine, they are separated by a group of marine origin, generally calcareous. This is termed the Muschelkalk, but of it no trace occurs in Britain. In the Triassic period probably the more northern part of the European area, including much of Russia, was a lowland region, occupied by the deltas and estuaries of rivers, by lakes, or by seas, which were almost, if not entirely, cut off from the open ocean.

But in the more southern part very different conditions prevailed. Early in the Trias, and throughout the whole period in some places, a highland, if not a mountainous, region occupied the site of the

Western and Central Alps, but from it the sea deepened rapidly eastward and southward. Instead of the sandy Bunter and marly Keuper of the northern region, we find in the Eastern Alps huge masses of limestone and dolomite, very probably formed by coral reefs and their *débris*. From these the grand cliffs and towers of the Dolomite Mountains have been sculptured, an Alpine region for long almost unknown to English travelers. This series of distinctively marine deposits occupies a large area all round the present Mediterranean Sea, and extends for a long distance into Asia.*

In parts of Germany and in Russia the break between Trias and Permian is not strongly marked, while in the most eastern part of the Alps the latter sometimes rest in order of sequence on marine (upper) Carboniferous deposits. In this district obviously marine conditions were persistent for a long period, but in Europe, as in Britain, the physical geography of very considerable regions was profoundly modified at the close of the epoch when the Carboniferous system was deposited. The changes will be, perhaps, most readily appreciated if we give a brief summary of the geological record from the beginning of the last-named period, "generally marine in the earlier, and fresh water in the later part." Throughout physical conditions similar to those of Britain prevailed over the Franco-Belgian area, and extended more or less interruptedly into Russia. The southern boundary of the sea is roughly indicated by Brittany, the Auvergne uplands, and the Western and Central Alps—while it flowed over the extreme east of this chain, and covered a very large part of Russia. But in other parts of the Alps beds of fresh-water origin may be found, which have been formed, as in Britain, over a much wider area than the marine deposits. Here a highland, if not a mountain, district already existed, in which dark carbonaceous rocks were formed, these sometimes being coarse breccias or conglomerates, but sometimes containing thin seams of coal. The Carboniferous period over a large part of Europe was closed by a great series of earth movements. The crust, not only in Britain, but in the northern half of France and Germany, was bent into a series of huge folds, the axes of which extend, roughly, from west to east, and the Alpine region was similarly affected. Throughout the Permian and most of the Trias a large part of this region, west of the head of the Rhone valley, was

* The Rhætic beds in the northern area resemble, but are better developed than, those of England; in the southern they are mostly dolomites, like the representatives of the underlying Keuper.

a mountainous mass of land. In connection with these flexures, perhaps as one result of them, volcanoes broke out in many places; enormous masses of lava and ash were discharged in parts of Central Germany, as Thuringia, Saxony, and Bavaria, of Bohemia, of the Eastern Alps, and for some distance westward along the southern margin of the present chain. These volcanoes were most active in the earlier part of the Permian period, but in some regions, as in the Alpine district around Predazzo, they were not extinct even in the Triassic. But afterward, throughout the whole of the Secondary era, Europe was practically free from volcanic disturbances. In the later part of the Permian period terrestrial conditions or seas, more or less separated from the open ocean, seem to have prevailed north of the Alps, including much of Russia, so that the history of this region differed but little from that of Britain.

If a line be drawn roughly across Europe from the Black Sea to the North Sea, it divides the continent into portions, which, after Carboniferous times, passed through very different phases. On the more eastern side the changes were comparatively inconspicuous. The deposits indicate an oscillation between shallow seas or salt lakes and low-lying lands. But on the more western side the physical geography was completely revolutionized. From La Vendée to the north of England, from the coast of Kerry to the neighborhood of the Elbe, that immense group of flexures has left its mark on all the Primary rocks. Its effects have been detected, as already stated (p. 380), in borings beneath the valley of the Thames. The buried mass shows itself from under the Secondary rocks between Calais and Boulogne, and can be tracked eastward by a line of collieries through Northern France into Belgium. To these movements we owe the making of that vast highland district in which the glens of Kerry and the ravines of the Ardennes, the dales of Yorkshire and of Eastern Belgium, the coast scenery of Cornwall and Devon, of the Channel Isles and Brittany, have all been sculptured. In the Alps also the Carboniferous rocks are sharply infolded among the crystalline schists; and in more than one place, as at the base of the Tödi or in the valley of the Upper Romanche, the lowest Secondary measures may be seen resting on the denuded edges of the broken folds. The interval between the later Carboniferous deposits and the earliest of the Trias is so long that the flexures which differ in direction may possibly differ in date. Mention has already been made of this in regard to Britain.* Some of

* See p. 370.

the Alpine flexures also appear to have run more nearly north and south.* But be this as it may, the changes in the northwestern and west-central regions were prodigious, for these great folds not only had been formed, but also had been profoundly sculptured before Triassic times. Indications of this are afforded in Britain; they are even more striking in a geological map of France. Brittany and La Vendée are composed of huge folded masses of Primary and Archæan rock, the outcrops of which trend generally rather to the south of east; on that side they are buried beneath Secondary strata, which cross them almost at right angles. Hence not only must the upland masses on both sides of the English Channel have been formed, but also the broad interval between the highlands of the Ardennes and of Armorica, and the narrower one between the latter and Auvergne, must have been excavated. It was not so much a change as a revolution in physical geography, which in many parts of Europe separates the last record of the Primary from the first record which is in complete continuity with the Secondary era.

In pre-Carboniferous times it becomes more and more difficult, owing to the complexity of the details, to tell, in a few words, the story of the making of Europe. But it is probable that the crystalline masses of Scandinavia and Brittany, like those of Scotland, of Auvergne and the Cevennes, of the Vosges and Schwarzwald, of Bavaria and Bohemia, of Spain and Portugal, and even of some parts of the Alps and Pyrenees, with other districts near the Mediterranean, severally indicate the position of land surfaces from a very early period in the history of the globe. In all these regions the older Primary (or Palæozoic) rocks either are wanting or, if present, are evidently shallow water deposits infolded among crystalline schists of still earlier date.

In Devonian times a sea, with which that of Southern England was connected, extended over much of Northern France and Germany into Russia. In the northwest of the last region the association of rocks which recall the Old Red Sandstone type of Wales and Scotland with marine beds, like those of Devonshire, indicates an oscillation between marine and more or less terrestrial conditions. Indeed, a very considerable area of the northern half of Europe, including much of Germany, appears to have been occupied by a rather shallow land-girt sea, which was deepest toward the middle

* Possibly the Ural range may have been formed at this period, though an earlier date is assigned to it by some geologists.

of the period. There was also sea in the neighborhood of the Eastern Alps, Bohemia, and Poland, and in Spain, with Portugal.

The Cambrian, Ordovician, and Silurian deposits of Southern Scandinavia and the adjacent regions of Russia are unusually thin and unchanged, being in places still comparatively incoherent. From this we should conclude that, if the Scandinavian region even then formed a shore line to the sea, it contributed but little sedimentary material. In most parts of Europe limestones are not abundant in the earlier Primary deposits ; muds and sands indicate the prevalence of physical conditions generally similar to those of the British Isles, the drift of sediment, in some cases, being evidently from the west. In the more central parts of Europe beds of Early Primary age have not been identified, except in the more eastern portion of the Alpine region. A far-spreading sea evidently extended from the British Islands across Northern France (so as to include Brittany), Belgium, the hill regions of Southern Prussia (*e. g.*, the Harz, Thuringia, etc.), whence it most probably stretched across Poland and overflowed the greater part of Northern Russia ; perhaps also it turned southward into Bohemia. Sea also covered Spain, and extended during part of the time eastward as far as Sardinia, but there is no evidence that this was connected with the more clearly defined northern marine area. The fauna, and to some extent the general character of the older Primary deposits in Bohemia, agree more nearly with those of Southern Europe than with those belonging to the Anglo-Scandinavian sea. In Norway, as in the Scotch Highlands, beds somewhat older than the Cambrian may be identified.

To conclude : The evidence which has been briefly summarized indicates that many of the European highlands have existed, as physical features, from very early times ; that the present Mediterranean is a remnant—perhaps representative of the deepest parts—of a fairly persistent oceanic area, also of great antiquity and of wide extent ; and that in the north-central region (including much of Russia), defined on the north and west by the crystalline masses of Scandinavia, Northern Scotland, and Ireland, with possibly the extremity of Cornwall and Brittany, there was a constant struggle for mastery between sea and land, the former, on the whole, predominating. Further, it may be inferred that in this region the movements in a downward direction produced the most conspicuous effects during the Lower Carboniferous, the Jurassic, and the Cretaceous times, while in Europe generally the earth's crust was

most markedly folded and disturbed at the end of the Carboniferous, of the Eocene, and of the Miocene periods. But the movements which affected Britain at the beginning and at the end of the Silurian, though now less conspicuous, owing to great subsequent denudation, were probably once of no small importance, and formed parts of flexures which extended over much wider areas.*

At the present time the Asiatic continent consists of three regions, very distinct in their physical geography—namely, that of the southern peninsulas, that of the central mountain chains and elevated plateaus, closely associated with which are some well-marked basins, and lastly, that including the northern steppes and plains. Of these the most stupendous in its features is also, on the whole, the most modern. Of the northern plain but little is known, and not much is likely to be ascertained owing to the vast morasses (*tundras*) and the forests which cover so much of the Siberian lowland, but the geology, at any rate in the more western part, is probably related closely to that of Russia on the opposite side of the Urals. In the southern steppes various Primary rocks come to the surface, but there are few or none of later date, so that much of Southern Siberia has been a land mass continuously from very ancient days, and almost all was above water in the Tertiary era.

But during much of the time the region to the south of this, the great zone of mountains and plateaus, was under water; though in the peninsula of Hindustan we find traces of a very ancient land mass, of which Ceylon formed a part. Large areas are occupied by crystalline rocks and schists, probably Archæan, which here and there are overlain, especially in the south, by tracts of Primary rock. North of this region a sea, in Secondary and earlier Tertiary times, appears to have overspread the area now occupied by the greatest mountain masses in the world. To this sea we have already referred.†

* The disturbances which have affected the European regions, with other portions of the globe, were worked out in much detail by the late Professor E. de Beaumont, and a revised account of his results is given by Professor Prestwich ("Geology," part i. ch. xvii.). But the genesis of mountain chains was certainly a more complicated process than the former supposed, so that I have preferred to direct attention only to the more important and best established movements. When we find that a comparatively modern chain, like the Alps, is the result of at least two fairly distinct sets of movements in the same general direction, and has incorporated with it fragments, as they may be called, of earlier mountain masses, themselves produced by more than one set of disturbances, acting apparently by no means in the same direction, we begin to realize how complicated these questions speedily become, and how much more evidence must be obtained before the puzzling record of ancient physiography can be fully deciphered.

† Pp. 409, 412.

It extended from Central Europe across Syria, Asia Minor, Persia, and the whole region of Northern India, Thibet, and Western Mongolia. Here and there deposits of the Primary era may be detected, but very often deposits of Secondary, occasionally even of Tertiary, age rest on ancient crystalline rocks. This is the case in Syria and in parts of Arabia, Persia, etc., and among the Himalayas and Karakorams Secondary and Early Tertiary sediments, as in the Alps, are infolded with rocks presumably Archæan in age. The bed of this sea, as already said, has been elevated in places full 16,000 feet since the end of the Eocene period. When the sea existed, China, like most of India, may have formed land. Here also old crystalline rocks and schists are found; these apparently sank down gradually during the Primary era, for among them are deposits of various ages till somewhat later than the Carboniferous period.* Volcanic rocks are rather abundant, while the curious deposit called loess† covers large districts. On the whole, it is probable that the great belt of water which once crossed Asia and united the Atlantic with the Pacific passed in the direction of Burmah and Siam, where newer rocks seem to exist. Even after the great Central Asian chains were formed, a shallow sea still separated for a time their southern slopes from the Central Indian land, but it gradually retired when the great detrital deposits of late Miocene or Pliocene age were upheaved, as also happened on the borders of the Alps.

The information in our possession is insufficient to elucidate the complexities of the mountain region of Central Asia. Its connection with Europe is indicated by the plateaus and ranges of Turkey in Asia and of Persia, and by the more sharply defined chain of the Caucasus, but the mass rises more grandly as it approaches the Pamir plateau, "the roof of the world," and forks out thence like the fingers of a hand. Baron von Richthofen, in his classic work on China, distinguishes the following mountain systems in the mid-Asiatic region. Commencing from the south, they are:

(1) The Himalayan system (including the Karakorams). The axes of this run toward the southeast, in the neighborhood of the Pamir plateau, and gradually curve round to the east as the ranges approach the longitude of the Lower Ganges. As the Indus and Brahmapootra rise at the base of the Karakoram chain, and run for

* The coal fields of this age are no less extensive than valuable.

† P. 91. See also *Geological Magazine*, 1882, p. 293.

a long distance respectively west and east between it and the Himalayas before cutting through the latter, it is clear that, as in the case of the Bernese Oberland,* the first-named chain is the older, and that this system is the result of more than one set of movements.

(2) The Kuenlun system, the axes of which run slightly to the south of east.

(3) The Thian-Shan system, the axes of which run approximately E.N.E. Seemingly connected with this are not only the mountain chains which extend far in the direction of Southern Siberia, but also the *massifs* to the southwest of the Pamir region, of the Hindu-Khush and other ranges in Persia, Afghanistan, and Beluchistan. If so, this system is geographically of the greatest importance, for it may be said to extend almost from the Arabian Sea to Behring Strait.

(4) The Altai system has an E.S.E. trend, and seems in places to inosculate with or intrude upon that of the Thian-Shan. This set of disturbances also affects a large zone, generally on the western side of the later system, and is continued in the ranges about the head waters of the Amu Daria and Syr Daria, as far as the mouth of the Persian Gulf.

(5) The Chinese system has a northeastern trend, and affects the regions on both sides of the Kuenlun, and so eastward into China proper.

(6) The "Hinter" Indian system, which runs through Burmah to the Malayan Peninsula, trends rather to the east of south. This seems to inosculate with the Himalayan system, very much (to compare small things with large) as do the mountains of Dalmatia and Istria with the eastern portion of the main Alpine chain.

It would be rash at present to attempt to indicate the relations or exact ages of these chains; but the fact that not only some Primary and Secondary, but also Early Tertiary, strata occur immediately west of the Thian-Shan, about Lake Issyk-Kul, and in the mountain *plexus* northwest of the Pamirs, makes it probable that most, if not all, these chains, in their present form, are no older than the Alps, though, like them, they may include remnants of earlier mountain regions. Among them, as already stated, are some of the loftiest summits in the world, the highest peaks being in the Himalayan system; but points in the Hindu-Khush, the Kuenlun, and Thian-Shan chains sometimes rise well above 20,000 feet. The

* P. 411.

plateau of Thibet is generally full 12,000 feet above sea level, and that of Gobi some 4000 feet. The uplift of this vast central region seems to have determined the course of the chief rivers of Asia. The middle portion, between the Karakorams and the Thian-Shan, on each side of the Kuenlun chain, is a region of inland drainage; then from its eastern side the waters flow, often rather circuitously, to the Pacific coast. The Black Sea, the basins of the Caspian and the Sea of Aral receive most water from Russia and Western Siberia, but as the flanks of the Thian-Shan are approached the rivers begin to take a northward course to the Arctic Ocean. The fact that in Southern Hindustan the main rivers rise on the flanks of the Western Ghauts, and cut through the Eastern Ghauts on their way to the Bay of Bengal, indicates the superior antiquity of the former range.

The long chain of volcanic islands which borders, though at a distance, most of the eastern coast of Asia, and the fact that the crystalline schists, etc., which form part of the mountains of Japan bear signs of intense pressure, indicate that along the western zone of the Pacific Ocean folds have been forming, and the frequent eruptions and earthquake shocks suggest that the process has not yet ended.

The geology of vast regions in Africa is still a blank, though during the last twenty years our knowledge, both in the north and south, has been much augmented. What has been said of Western Asia applies generally to Egypt and to a considerable tract inland from the north coast of Africa. This was once overflowed by an ocean of which the Mediterranean Sea is a remnant. But during much of the Primary and Earlier Secondary time a great part of Northern Africa was probably above water, for over a large area nothing is found (except some small patches of Carboniferous rocks) older than Jurassic time, and in many places a sandstone, slightly earlier in date than the Chalk of England, rests upon crystalline schists or igneous rocks of great antiquity. After these times it was overflowed by the sea, which already has been mentioned. The Atlas range, which forms a southern boundary of this region, consists of a crystalline axis followed by masses of eruptive igneous rock, and by sedimentary deposits, probably of later Secondary age. The date of its upheaval seems to be uncertain, but most probably it is coeval with that of the Alps. In the more central regions, such as Abyssinia and that about the White and Blue Nile, we still find a floor of crystalline rock overlain by sediments, such as Jurassic

limestones, and sandstones of an earlier age. The Tertiary sea may have overflowed for a time the eastern side of the continent as far as Somaliland, but a very large part of Central Africa, including almost all that lies to the south of the fifth parallel of north latitude (the narrower portion), consists of rocks of either Primary or Early Secondary age, beneath which a crystalline floor is sometimes exposed. South of the Orange and Limpopo rivers we find but little that is later than the earliest part of the Jurassic period, Triassic rocks occupying considerable areas.*

Active volcanoes or lofty mountain chains are almost entirely absent from Africa; the highest summits are indeed volcanic, but their fires, as at Kilimanjaro, Keenia, and Ruwenzori, are generally extinct. The most mountainous ground is often near the coast, much of the interior being a fairly elevated hilly plateau, often averaging 4000 feet above the sea. The highest summits of the Atlas may reach about 12,000 feet, but in other parts of Africa if anything rises above some 10,000 feet it is a volcanic cone.† In many districts igneous rocks are interbedded with or break through stratified deposits of various ages.

The courses of the great rivers of Africa are remarkable, and suggest the possibility of the continent being formed by the combination of a series of masses originally insulated. The elevated lake region of Central Africa, the physical history of which has not yet been investigated, sends off the Nile system to the north, the Congo system to the west, and the limited Shiré to the south. Occupying the angle between the basins of the first and the second is a large area of inland drainage, to which succeeds the basin of the Niger. Both this river and the Congo follow rather singular paths; the latter one sweeps northward in a great curve to beyond the equator, and then returning reaches the sea more than five degrees south of it. The Niger, rising not very far from the west coast, runs eastward and then southward, to flow at last into the Gulf of Guinea. Thus the Kong and Saraga mountains on the north of that gulf and the Sierra Complida on the east of it seem to have

* The celebrated diamond mines of Kimberley are in the Karoo shales, which belong to the Trias. Some igneous rocks have broken into these shales, and the diamonds are found in rude circular areas, which appear to have been somewhat affected, perhaps by water or by steam.

† The height of Kilimanjaro is 19,680 feet, of Keenia about 18,000 feet, and of Ruwenzori nearly the same. The Cameroons, near the Gulf of Guinea, are about 13,700 feet, and are also volcanic.

diverted the rivers from their natural courses. South of the outlet of the Congo is another mountainous mass, similar to that last named. Its importance seems to be indicated by the long course of the Zambesi, to which it contributes; and the inland basin of Lake Ngami possibly marks the position of a channel which once separated this Angola district from the uplands of the central lake region. South of the Limpopo the mountains of the east coast become dominant, and the main flow of water is westward. The curiously even outline of the whole African continent south of latitude 30° N. suggests that for a considerable time, geologically speaking, it has undergone but little disturbance.

The physical structure of North America, on the whole, is more simple than that of Europe. Much of the continent is a vast hilly plateau, which occupies all the northern region, except for a certain distance on the western side, and which gradually sinks down to the wide plains drained by the Mississippi and its tributaries. These gradually contract toward the south, ultimately ending on the shore of the Gulf of Mexico. This region of upland and plain is separated from the Atlantic by an ancient mountain chain, from the Pacific by one of grander size, more complex structure, and more modern date. Thus the continent consists of three rather distinct regions, each of which we proceed briefly to describe.

In the northern or northeastern region Greenland and all the islands on the American side of the Arctic Ocean may be included. Here, over a large area all about Hudson's Bay, the rock for hundreds of square miles is mostly Archæan—gneisses, schists, and igneous masses of great antiquity. These, however, in many places, especially toward the southern side, are overlain by Cambrian, Ordovician, Silurian, and occasionally even later rocks of the Primary series. The first occupies the most limited areas, but rocks of yet earlier date (Huronian) also occasionally occur. This region, as a rule, is not much affected by great dislocations, sharp folds, or other indications of severe pressure. The sedimentary deposits seem to succeed one another with tolerable uniformity. Among them the Trenton limestone (about the age of the Bala beds of Britain) and the Niagara limestone (the equivalent of the Wenlock) are thick masses of pure calcareous rock, indicating long-continued accumulation in quiet seas teeming with life. Here, then, we have the core of the American continent—a comparatively undisturbed portion of a region which at a very early epoch was above water, for a time oscillated between land and shallow seas, and gradually returned to

its former condition. So far as we can judge from what has been revealed by the great earth movements on the western side of America, these crystalline rocks continued to form a land surface there till rather late in the Primary era, for, as a rule, the earlier representatives of that era are not very common, and in some cases strata of Secondary age rest directly on rocks presumably Archæan.

In the more southern part of Canada and in the Eastern States the history of the region in the Carboniferous period seems to have been very much the same as that of England; alike in the lower and upper part, in the Limestone and the Coal Measures, there is great similarity. As in Europe, so here, that period appears to have ended with an epoch of severe disturbance.* A mighty thrusting force, acting apparently from the direction of the present bed of the Atlantic, formed the great group of flexures which gave rise to the Appalachians, Alleghany, and other ranges bordering the Atlantic from Alabama to Newfoundland. By these movements the eastern coast of the American continent was defined. Only along a narrow littoral strip in the States, and over a rather larger area of comparative lowland about the Gulf of Mexico, have any important additions been made. During the Triassic, and even the Jurassic, period this continental region extended very far west, almost to the Pacific coast, though in the latter system deposits are found which indicate that the sea occasionally trespassed for a considerable distance inland. This, however, is true of the more southern rather than of the more northern region. Professor Dana believes the first development of the Sierra Nevada as a mountain range to date from the end of the Jurassic period, after which time a downward movement began, so extensive as to affect North America generally, west of a line running roughly from Lake Winnipeg to Texas. As a result, almost the whole of this region was covered by a shallow sea, the bed of which slowly sank. In this the great masses of sediment were deposited, which are now upraised in the mountain regions of the Western States. "As the era drew toward its close, the subsidence appears to have intermitted for long intervals, with perhaps some upward movements, so that the land became slightly emerged. Later, the eras of intermitted subsidence became greatly prolonged, so that immense peat beds were formed from the vegetation growing over the quiet marshes; but between, in the intervening eras,

* It is stated that there were some important disturbances in the Green Mountain region between the Ordovician and Silurian.

during which the sinking was renewed, thick sand beds and clay beds were made, containing marine or fresh-water shells, or both commingled. . . Thus gradually, so far as rock making was concerned, the Cretaceous era ended and the Tertiary age began." *

Gradually, toward the end of the Eocene, this period of quiet movement, of deposition mainly terrestrial, came to an end, and the development of the vast mountain region of the West began. This was a protracted process, but in it epochs of greater intensity have been noted. The first appears to have occurred early in the Eocene period, since it disturbs the Laramie and earlier deposits in two distant regions, one west of the Sierra Nevada, the other east of the Wahsatch. The second epoch closed the Eocene, and practically defined the eastern half of America, for there marine Miocene deposits are restricted to the Atlantic border. By these movements also the Rocky Mountain regions were affected, but not very greatly. The third epoch closed the Miocene, uplifted yet more a vast area in the Rocky Mountain region, and produced the Coast Range, parallel with the Sierra Nevada. During the Miocene period "there is proof that mountain-making pressure, from the Pacific direction, had acted with energy against the continental crust, in the occurrence of extensive areas of igneous rocks over the Pacific slope and part of the summit region, and the vast areas of trachyte and dolerite show that immense regions were flooded by outpourings from fractures at successive times. These eruptions continued to take place over those regions at intervals from the close of the Miocene even into the Quaternary age, and they have not even now altogether ceased." † It must not be forgotten that the great volcanic outbursts, which affect the region from Western Greenland to Scotland, and even to Northern Ireland, were also of Tertiary age, or that the submarine plateau which runs beneath the Faroës and Iceland appears to have formed for a considerable time a link of land between the northern continents of the Old and New World, and to have parted the Arctic from the Atlantic Ocean.

Thus the river systems of Western America, like most of those in Europe, date from the later part of the Tertiary era. That of the St. Lawrence may probably claim a greater antiquity, and so possibly may some part of the Mississippi. During the Glacial epoch a great ice sheet covered most of Canada and much of the

* J. D. Dana, "Manual of Geology," p. 520, second edition.

† J. D. Dana, "Manual," p. 524.

northern States, and its moraines have been identified by American geologists, in some places, to the south of the 40th parallel of latitude.* The continent has not been at rest since the process of mountain making ceased, for there has been considerable depression in the lake region of Canada and the United States,† and the deeply submerged channels of the St. Lawrence, the Hudson, and other rivers of the eastern coast indicate that this region, probably during some part of the Glacial epoch, was upraised at least 2000 feet above its present level. Still the continent of America, as a whole, appears to have been little changed since the beginning of the Pliocene era, and the geography of all its northern portion, if no more, indicates that at the present time the level of the land generally is lower than when its chief physical features were sculptured.

The South American continent slightly resembles that of Africa in outline, though on the whole it has a simpler structure. The Caribbean Sea, with its chain of islands as an eastern boundary, suggests some analogy with the Mediterranean; the land link between the southern and the northern continents, geologically speaking, is comparatively recent, and the date of the final severance between Atlantic and Pacific water is still a matter of dispute. Much yet remains to be learnt of the geology of this continent, but some facts of great importance are now fairly certain. The chain of the Andes forms part of that group of flexures which borders the Eastern Pacific from north to south. Yet though so stupendous a feature in the continent, it is comparatively modern. One much more ancient is indicated by the great plateau of Brazil, which stretches inland from the Atlantic as far as the *Selvas* of the Amazon on the north, and the *Pampas* of the Rio de la Plata on the west.‡ It consists mainly of ancient crystalline rocks, covered in places by Primary strata. The plateau of Guiana also, between the Amazon and the *Llanos* of the Orinoco, is a smaller mass of like composition. As there are some indications that the Primary strata cross the Amazon valley, these two plateaus, at an earlier period of their history, possibly may have formed a single continental mass. This, no doubt, had its disturbances in days of old, but for ages it has been comparatively at rest, and the scene of

* In one place it came almost 50 miles south of lat. 38°.

† Page 140.

‡ The *Selvas* are forest-clad lowlands, the *Pampas* and the *Llanos* grassy lowlands in the several river basins.

action has been shifted to the other side of the continent. Here huge volcanoes,* often rising from 17,000 to more than 20,000 feet above the sea, crest the chain of the Andes, but its body consists mainly of sedimentary deposits, with some crystalline rocks, probably ancient. Both have suffered from severe pressure in the process of mountain making, by which they have been raised not unfrequently to altitudes of thirteen or fourteen thousand feet. Among them deposits of various ages, from the Ordovician to the Jurassic, have been identified, so that probably this region of the earth's surface, or at any rate considerable parts of it, as in the case of the Rocky Mountains, may have been submerged during a large part of the Primary and Secondary eras. But, so far as we know, Tertiary deposits do not form an important element in the constituents of the *massif.* Ancient volcanic rocks indicate great eruptions long prior to that era. Elevated plateaus are inclosed between the ranges, and from lat. 5° N. to 40° S. the watershed generally does not fall below 11,000 feet, and is often much above it. Certain huge spurs, which run roughly parallel with the south shore of the Caribbean Sea, may be the result of thrusts connected with this basin. The courses of the great rivers are remarkably simple. The headwaters of the Orinoco, the Amazon, and the La Plata all start from the flanks of the Andes; the first and second run eastward on either side of the plateau of Guiana, and the third is compelled by the vast plateau of Brazil to take a course almost due south. Owing to the physical structure of the continent already mentioned, the basin of the Orinoco, for a limited distance, is separated from that of the Amazon by a low and ill-defined boundary, and the same is true of the basin of the latter river and that of the Rio de la Plata. The greater part of the coast line of this continent, at any rate south of the Orinoco River, resembles that of Africa in its regularity; but from about lat. 40° S. on the west coast, and perhaps as much as 10° further north on the east coast, the abundance of islands and fjords indicates that the whole region has sunk down for some hundreds of feet at a date geologically recent.

Such an admirable outline of the geology of Australia is given by Mr. Wallace† that I venture to quote his account, with some abbreviation. We may conclude, he says, "that the eastern and the western divisions of the country first existed as separate islands,

* Comparatively few of these are still in activity.

† "Island Life," p. 464.

and only became united at a comparatively recent epoch. This is indicated by an enormous stretch of Cretaceous and Tertiary formations extending from the Gulf of Carpentaria completely across the continent to the mouth of the Murray River. During the Cretaceous period, and probably throughout a considerable portion of the Tertiary [era], there must have been a wide arm of the sea occupying this area, dividing the great mass of land on the west—the true seat and origin of the typical Australian flora—from a long but narrow belt of land on the east, indicated by the continuous mass of Secondary and Palæozoic formations already referred to, which extend uninterruptedly from Tasmania to Cape York." As no Tertiary deposits have been found in this area, it may have extended from north to south without a break. It consists of a basement of ancient crystalline rocks, supporting Palæozoic and Secondary formations, the latter being developed on both sides the central range, the former including the important coal fields of the Newcastle district, which are approximately coeval with those of Britain. So this region must have been almost submerged in the Secondary era. The western land consists of a large mass of "granite, 800 miles in length by nearly 500 in maximum width," which "certainly was once buried under piles of stratified rock, and then formed the nucleus of the old Western Australian continent."

The group of islands constituting New Zealand seems to have been much augmented during the later part of the Tertiary era. These upward movements are probably connected with the great outbursts of igneous rock* which characterize several localities. They continued to a very late date, geologically speaking, though undoubtedly the physical geography of the southwestern part of the Middle Island and the more northern part of the North Island point to still later movements in the opposite direction. Speaking generally, New Zealand exhibits a fairly continuous section of rocks belonging to the three geological eras, and the oldest of these seems to rest upon crystalline rocks, almost certainly Archæan in age. The last named are chiefly exhibited on the western side of the islands. Is it possible that here, and on the eastern margin of Australia, we find the last fragment of a very ancient mass of land now fully 1200 miles apart? The intervening sea is deep, but its bed slopes down slowly from the western shore of New Zealand, so

*There is much comparatively modern igneous rock in Australia, but no volcanoes are still active.

that an area far broader than the islands is included within the thousand-fathom line, from which one long spur is thrown off toward Queensland, and another actually links on to the north of Australia by way of New Caledonia.

A large number of the Oceanic Islands consists either of volcanic rock or of recent calcareous deposits, commonly connected with coral reefs. But in a certain number of cases not only those of great islands, as New Zealand and Madagascar, but also those of smaller size, such as the Chatham, Tonga, and Marquesas islands, New Britain, the Fiji, and Solomon archipelagoes, etc., various deep-seated igneous rocks or clay slates and old sandstones have been observed. Thus the general rule is not without exceptions, and in other cases the superficial deposits may conceal masses of much more ancient rocks.*

*As remarked by Mr. A. Harker, *Geological Magazine*, 1891, p. 252.

CHAPTER VI.

A SKETCH OF THE EARTH'S LIFE-HISTORY.

THE study of fossils brings before our eyes the fauna and flora of the globe during past ages. It has led the way to two general conclusions: the one, that the disappearance of any group of living creatures and the introduction of another has been a gradual process; the other, that the newer types are related more or less intimately to the older. The first conclusion is a certainty; not the slightest evidence can be found of any catastrophic destruction, over the earth as a whole, of its living tenants, or of a corresponding creation of a number of new species, whether of plant or animal. The second conclusion has a high degree of probability; it cannot as yet be regarded as demonstrated, but the arguments against it are far outweighed by those in its favor.

What life is we do not know; of how it begins we are equally ignorant. When the curtain draws up on the first act of the world's drama of life, the stage is already occupied, and no prologue speaker comes forward to narrate the events which have led up to the situation. But just as we should infer from the opening scene in a drama preliminary incidents and influential motives tending to the development of each one of the characters, so we infer from a study of the nature and structures of the creatures which are the first discovered that they were preceded by others and were in some way themselves the outcome of circumstance. Legends of olden time tell of people who sprang from the earth full grown and nations which were autochthonous. Science, even in her dreamland, knows of none which have not a past history and a long line of ancestors. Life doubtless had a beginning, and the first forms were probably of an embryonic character; but of these all vestiges have been completely effaced.

In deciphering the record of the rocks we find that the story which is told by its latest lines differs little—if at all—from the present history. For instance, in the coarse flint gravels which are found at various elevations—commonly less than a hundred feet—above the present beds of rivers, more especially in the south-

eastern half of England, the remains of a few creatures now extinct have occurred. When all the land on the site of London between the present margin of the Thames and the line of the Euston Road was washed by a broader and more rapid river, then the savage races who inhabited its banks hunted a huge elephant and a rhinoceros, both of which have since disappeared from the earth. In that, however, there is nothing strange. Even now many of the larger animals—those which are either more profitable or more hostile to man—are becoming yearly more scarce. The wolf has disappeared from Britain,* the lion from Greece and Syria, the hippopotamus from the Lower Nile; the bison, the fur seal, the African elephant, and a host of other wild animals are far rarer now than they were in the last century, even in the last generation. Within two centuries the dodo, the solitaire, the great-auk, Steller's manatee, and a few other animals have become actually extinct, vanishing before the face of man—a destroyer more ruthless than any wild beast, for it slays only for appetite, he for greed of gain or lust of slaughter, both insatiate. The older any extinct type is proved to be the less closely it resembles any of those which still survive. Still its divergences from them appear to be in accordance with some rule, and not in any sense spasmodic and eccentric. Geology, in fact, demonstrates the actual existence in a remote past of creatures not less strange than the monsters of legends. So strong, indeed, is the likeness in some cases that one could fancy that, as stories of giants sometimes grew out of discoveries of the bones of mammoths or other large mammals, so the dragon killed by St. George, or the griffin portrayed by the Lombard sculptor,† had been constructed by some prehistoric Cuvier or Owen from relics which had been actually found. But until a remote epoch is reached geology reveals nothing widely different from existing forms, and it never exhibits anything in which a general correspondence with some known type is associated with some bizarre deviation. It finds no place for the Faun or the Satyr, the Merman or the Centaur, the Cyclops or the "men whose heads do grow beneath their shoulders." It unfolds—and the conviction of this deepens simultaneously with the

* The last wolf is said to have been destroyed in Scotland in 1680, and it lingered about thirty years longer in Ireland; the reindeer was living in Caithness in 1159, the brown bear was probably destroyed by about the tenth century, the beaver disappeared from Wales shortly after the twelfth century, and the wild boar became extinct before the reign of Charles I.—Dawkins, "Cave Hunting," ch. iii.

† Ruskin, "Modern Painters," part iv. ch. viii.

widening of knowledge—the working of mighty laws, the operation of co-ordinated forces. Though the living form may be plastic as clay in the potter's hands, yet in Nature's workshop no apprentices can play their elf-like tricks, for one master mind directs alike in small and great.

As the pedigree of life is followed back in geological history, the ancestry of many forms now living can be distinctly traced, but not a few are found which appear to have died and left no successors. It is also made evident by a comparative study of past floras and faunas that the more remote they are from the present time the less marked, on the whole, is their resemblance to living types. Of the fauna which existed in the later part of the Tertiary era the great majority still survive, of the earlier one comparatively few. From the end to the beginning of the era the percentage of living forms steadily decreases, while that of extinct correspondingly increases. From the later deposits of the Secondary hardly a species—perhaps not a single one—has survived. During that era lost genera become more frequent, then families, and finally even orders. Still everything which is found, even in the earliest strata, presents some resemblance to existing types of life. In most cases, if not all, a skilled naturalist, if only a fairly perfect specimen were placed in his hands, would at once recognize its affinities with some of the orders which exist. The chief difficulties in the classification of fossil forms—apart from those caused by the necessary imperfection of the materials *—arise from their generalized character, as it may be called. They differ from every one of the existing groups, and yet present structures which form connecting links with several. These correspondences also, as a further study indicates, are usually of a more or less embryonic character; that is to say, they are still exhibited by life forms which are now perfectly distinct, but this is only in the earlier stages of their development; the resemblances which now disappear as the animal becomes adult were then stereotyped and became characteristic of the individual. To put the matter briefly and in homely phrase, many of the life forms of the earliest ages were merely overgrown babies.

Nature, as we have said, is the schoolmistress of all living creatures; and, harder than the sternest of all human pedagogues, she never spoils the child by sparing the rod or remits the penalty for

* It must be remembered that even the best preserved specimen only retains the hard parts of the organism.

any crying. The motto so well known to the Wykehamist seems to be writ large on the walls of her schoolhouse: "Aut disce, aut discede, manet sors tertia cædi," which may be thus freely Englished: "Change yourself as conditions change; begone elsewhere would you live as you did, or stay to suffer and to die." The choice is often only between the first and the last—the ill-fated creature is sometimes caught in the proverbial position between the fiend and the deep sea—for instance, to a shore crab the one is represented by the rising land, the other may be an actuality. So it must become a land crab or an extinct species; but, even where it has been able to migrate, the movement and the inevitable changes in condition,* though slight, produce their effects, and some variation is generally the result. The appearance of a new fauna or flora is indicative of a period of change. "Quieta non movere" may be taken as the motto of a species; yielding place is one of the results of specialization.

Earth's children are put at once to school; Nature is its mistress, and, though she takes her scholars from the breast, does not adopt the methods of the kindergartens. All creatures, by the discipline of life, by the endless influences of a changing environment, have been gradually developed, specialized, and molded till they have come nearer to the forms which at present exist. Organisms, like men, have a pedigree; even with our imperfect knowledge a family tree in most cases can be constructed for each particular group. This, no doubt, did we know the whole history, could be expanded so as to unite all living things and cover all time; then the analogy between the trees, genealogical and botanical, would be complete. As the latter rises from the soil under which its roots are concealed, none the less real because they are unseen, so the former would appear at the first epoch of geological history, supported in reality on an unknown and irrecoverable ancestry. As the central stem rises from the ground, it throws off, first one branch, then another; some of these evidently were never healthy growths, and speedily withered away; others, though they prospered for a time, have ceased to increase, and now are dwindling, if not actually dead; while others are still in full vigor, year by year putting forth leaf and flower, twig and fruit.

Among mankind the annals of a family are a history of failures and successes. This branch has gone to the bad, that has prospered

* Since probably hardly any two places in the world are exactly alike.

exceedingly. So it has been in nature. Her chronicle of life is full of examples of either fate. It is suggestive of endless analogies with the varied stories of human life, with the ups and downs of individuals and nations. Perhaps some day, when we know more, we may say more boldly than now "which things are an allegory," and perceive more clearly that in every phase of life's history, from the lowest to the highest, "through the ages an increasing purpose runs." In the narrow round of each man's life the memories evoked by turning over the portraits in an old photograph album are apt to be sad. There are so many who have failed in life, or have died young. Of such records the stone pages of nature's picture-book are full. Again and again we come across the remains of some type which obviously never was a success. Why and wherefore we are not told, but the fact is certain. The genera are few, and no one of them was ever represented by many species. The type was never numerous, even individually. For whatever time it may have struggled on—and the period, geologically speaking, usually is not very long—its members, like the conies, were always a feeble folk. Like some families among ourselves, they never make much mark in the world, and are not even prolific of paupers. A different fate attends another series of living creatures; these are never numerous, but they are extremely persistent; they are represented age after age by a limited number of species, and but seldom are individually abundant; they are apparently not very flexible, but they are strongly enduring. They resemble some of the "statesmen" and "dalesmen" of our northern agricultural districts, at any rate before the general upset of the last half century, when son succeeded father for almost untold generations, and the changeful influence of the outer world penetrated but slowly. Most people know the pearly nautilus;* it is not a very abundant "shell" at the present day. The genus in the past was always represented by a few species, and none of these ever swarmed in the sea, yet it may be traced back well into Palæozoic times. A creature with a bivalve shell, called *Lingula*, one of the living brachiopods, has a yet longer history, for it actually goes back into the Ordovician; and if a closely allied form (*Lingulella*) be included, as it was formerly, in the genus, it is one of the very earliest fossils which have yet been discovered in the Cambrian strata.

By other types of life an extraordinary fecundity and variability

* *Nautilus pompilius*, living in the Pacific, near the Moluccas, Fiji, and adjacent islands.

are exhibited. They were apparently very sensitive to external stimulus, and prompt to modify themselves accordingly. Thus the number of representative species is large, and the individual communities are numerous, but each species lasts for a comparatively short time. No better examples of them can be found than in the genus *Ammonites*, as formerly defined.* These creatures belong, like the nautilus, to the Cephalopods. Their shell also is chambered and coiled in a plane spiral with the whorls in contact, and the chambers are connected by a sort of pipe, or "siphuncle." This is dorsal in position—that is, placed against the outer "keel" of the shell—and the sutures, or lines, where the "septa," dividing the chambers, meet the shell, assume very complicated forms, somewhat leaf-like in outline. These are the most obvious points of difference from the nautilus; but their history in many respects is curiously diverse from that of this genus. In Northwestern Europe they make their appearance in the Trias, but the occurrence of a kindred and rather more simplified form indicates that even then the process of specialization was not quite complete, while forerunners of a more generalized character are found in the later members of the Primary series. Toward the end of the Trias the genus had got a firm footing, and it lasts all through the Secondary era. The number of species is very great, but their duration is frequently so limited (though their geographical range is wide) that no form of life is found more useful than the Ammonite for subdividing a group or a stage into zones. All through the Jurassic system the "zone of *Ammonites* so-and-so" is employed almost as confidently as a consulship or archonship in classic history. After this period the endeavor to adapt themselves to circumstances seems to become yet more marked. In Triassic and Jurassic times the family rarely departs from the "plane spiral" as its fundamental type of growth. But instances of deviation become commoner in the Neocomian, and frequent in the Cretaceous. Always there is a long row of

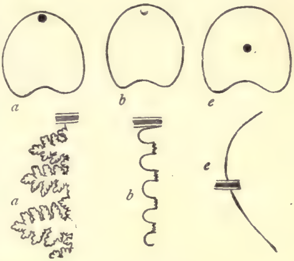


FIG. 145.—SEPTUM AND SUTURES OF (*a*) AMMONITES, (*b*) CERATITES (FROM THE TRIAS), (*e*) NAUTILUS.

* The genus is now split up into several genera.

chambers, increasing gradually in size, but this may be straight as a ruler, hooked like a walking stick, bent up into a plane or a helicoid spiral, the whorls being in contact, or separate, or arranged in some more complex pattern, intermediate between or combining certain of these. Then the family disappears. May it be compared to certain firms with a long and prosperous history, which have plunged, when the tide seemed to be turning against them, into reckless speculations, with bankruptcy as the final end? It is clear that no life form can maintain itself in the struggle for existence unless it possesses sufficient pliability to respond to changes in its environment; but appearances sometimes suggest that this may be carried too far, and the end precipitated by a premature exhaustion of vitality caused by the desperate efforts to escape the impending doom. At any rate, it seems certain that highly specialized forms are the more sensitive to external stimulus; hence they have the shortest duration in time, because they are either changed by evolutionary process, or else are brought to an untimely end. The latter fate is by no means uncommon; for the effects of any disturbance of the balance obviously may be more serious in a complex organism than in one of simpler structure. Forms of a low organization have an enormous persistency.* They are probably insensible to slight changes, and readily find, if forced to migrate, conditions suitable for their existence. But even in the cases where an organism is being modified it does not follow that any record of this will remain. In a time of active physical change denudation may alternate with deposition. Even when the change is brought about by a gradual subsidence, the development of one species from another may be difficult to follow. A new fauna seems more commonly to arrive like colonists, the older one migrating or becoming extinct before the invader. The new form may have been actually developed under conditions which were less favorable to the preservation of a record. The epoch of a nation's birth is not generally the most complete in its history. We know more of the decline of the Roman Empire than of the rise of the races from which modern Europe grew up.

But among all these changes one thing is noteworthy—there is no repetition. When once a type has become extinct, it is never reproduced either in the same or in any other part of the globe. It

* Foraminifera, for instance, have continued through several geological periods without any apparent change; but these creatures are so variable that it is difficult to say what defines a species among them.

is this which makes a classification by organic remains possible. "The order of succession established in one locality holds good approximately in all."* Another thing also may be noted. In Nature the saying "Ilka dog has its day" seems often to hold good. A particular order or family increases largely, and exhibits great powers of variation, after which it dwindles or disappears, when something else seems to take its place. For instance, the corals of the Palæozoic era differ so greatly in structure from those now living that a large number of them have been put into a different order. Again, there were times when among "bivalve shells" brachiopods swarmed and lamellibranchs were rare; the contrary is now the case. The trilobites had made their appearance at the dawn of geological history; afterward they increased and multiplied greatly, and then utterly disappeared. These instances may suffice; the list could be readily augmented.

Again, the great divisions of organic life seem to be affected in turn by tendencies to change. Each passes through an epoch of marked development, and then becomes comparatively stationary. It appears to lose its power of adaptation to circumstances; it becomes a palæontological Spain or Turkey. In such case it very often dwindles and vanishes from the scene, for in the animal world a nation is not kept in existence by the mutual jealousies of its stronger neighbors. But even where the vitality of a race is not exhausted, it appears to reach after a time the limits of variation, at any rate in the more important matters, and subsequent changes are specific rather than generic. Possibly certain types of the order or class have been produced which are fairly well adapted to the conditions of life dominant on the globe, and are thus able to remain until the vitality of the several species is exhausted; for in the biological, no less than in the physical, world the law of dissipation of energy seems to hold, and the race at last to die, as the individual may die, of sheer old age.

We cannot attempt in this volume more than a brief sketch of the succession of life on the globe, for any full description would require the introduction of too many technicalities. Beginning with plants, we must remember that a fossil flora is likely to be a very imperfect representative of the flora of any region. It will indicate the vegetation of the sea, the lake, the stream, the marsh, or the lowland generally; that of the upland and the mountain will be rarely pre-

* Huxley, Address to Geological Society, 1870. ("Lay Sermons and Addresses," X.)

served. The botanical record is probably even more fragmentary than the zoölogical. Plants naturally might be expected to have come into existence at least as early as animals. A consistent evolutionist would hope to find the germ of the subsequent "tree of life" in some embryonic form, which was neither plant nor animal, but was so destitute of definite structures that it could not be assigned with confidence to either. Of any such embryonic form we know nothing; moreover, plant remains that are beyond all suspicion are not found until we have passed through several chapters of the earth's history. In the Cambrian, it is true, numerous objects occur which have been called fucoids, because they were supposed to be seaweeds, and have received generic and specific names, but in no case is the identification with plants at all certain. It is just possible that some may be very imperfectly preserved stems or leaves, but the majority, more probably, are either inorganic structures, such as may be produced by running water, the filling up of shrinkage cracks and the like, or tracks which have been made by worms and other crawling creatures. Passing by these doubtful "seaweeds"—the only evidence in favor of the existence of plants in the whole of the Cambrian period—the first indubitable plant occurs in the Skiddaw (Arenig) rocks of Cumberland, and so was living at the beginning of the Ordovician. The genus is named *Buthotrephis*, and two species are supposed to occur. Its affinities are doubtful. Some think it an alga, others a rhizocarp, and a distant connection of the living Pillwort (*Pilularia*). The Ordovician system has furnished two or three other plant remains of uncertain botanical position, and even the Silurian has not proved to be very much richer.* In it rhizocarps are again found, but two of its plants must have attained to a considerable size. The botanical position of one called *Nematophyton* is doubtful; some consider it to be a huge seaweed; others, a conifer, or, at any rate, one of the gymnosperms. The remaining plant is regarded as a relative of the club-mosses (*Lycopodiaceæ*). These, however, are now lowly plants; this one was a tree.

In the Devonian system vegetable remains become much more abundant. In this country they are still comparatively rare, but a considerable flora has been recovered from various districts in Eastern North America—*e. g.*, from the neighborhood of Cape

* One of the most interesting discoveries was in the neighborhood of Corwen, by Dr. H. Hicks, about on the level of the base of the Wenlock group, or possibly the top of the Upper Llandovery.

Gaspé and Southern New Brunswick, in Canada, and from localities in New York, Pennsylvania, and Ohio. More than a hundred species, belonging to about ninety-five genera, have been described.* The vegetation of this period was closely related to that of the Carboniferous, so that in any general statement the two may be coupled together. The flora of the latter is a remarkably rich though a very singular one. Europe alone has afforded 176 genera and 1370 species, and in Great Britain plant remains have been furnished by all the great subdivisions of the system from the bottom to the top; but here, as in other countries, the flora of the older parts is less rich than that of the newer. The vegetation is peculiar. Much uncertainty still prevails upon several points, largely due to the imperfect preservation of the remains and to the difficulties in bringing the plants into line with existing divisions, but the following general statements represent the present stage of knowledge. Ferns, often tree-ferns, were abundant. Besides these, tall branchless stems, "exhibiting in habit of growth and fructification a close resemblance to our modern *equisetum*" † or horsetails, formed "dense thickets, like southern cane-brakes." These plants (*Calamites*) far outgrew their modern allies, attaining a height of some thirty feet. Not less common were a number of tree-like plants (*Lepidodendron*, *Sigillaria*), which appear to have been most nearly allied to the club-mosses (*Lycopodium*), but which occasionally rose forty feet above the ground. Spores and spore-cases, referred to these plants, are often abundant, and sometimes make up whole layers of coal. Similar plants are found in the Devonian rocks. The modern conifers were represented by a genus *Cordaites* and other plants,

FIG. 146.
CALAMITES CANNÆFORMIS.

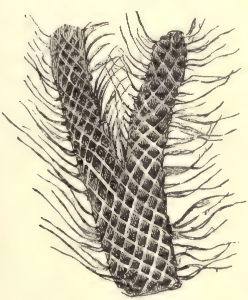


FIG. 147.
LEPIDODENDRON ELEGANS.

* Sir W. Dawson, "The Geological History of Plants," ch. iii. (International Scientific Series).

† Dawson, "The Geological History of Plants," ch. iv.

which appear, on the whole, to be most closely allied to some of the broader leafed yews, such, for instance, as the *Salisburia* or gingko tree of China; but these were less abundant than the forms already named, at any rate, in the swamps of the Carboniferous period; for of the vegetation of its highlands, as already said, we know so little that we may readily form a very incorrect idea of the vegetation of the earth as a whole.

The Permian rocks are not very rich in fossil plants, but the vegetation as a whole is related to that of the Coal Measures, though the latter obviously is beginning to give place to forms of more modern character and higher development. By the beginning of the Secondary era the change had become very marked. Here the "old Carboniferous forms of plants finally pass away, to be replaced by a flora scarcely more advanced, though different, and consisting of pines, cycads, and ferns, with gigantic equiseta, which are the successors of the genus *Calamites*, a genus which still survives in the Early Trias. . . The cycads are a new introduction. The whole, however, come within the limits of the cryptogams and the gymnosperms, so that here we have no advance. As we ascend, however, in the Secondary we find new and higher types. Even within the Jurassic epoch, the next in succession to the Trias, there are clear indications of the presence of the endogens, in species allied to the screw-pines and grasses; and the palms appear a little later, while a few exogenous trees have left their remains in the Neocomian; and in the Cretaceous these higher plants come in abundantly and in generic forms still extant, so that the dawn of the modern flora belongs to the Cretaceous."* According to Sir W. Dawson only twenty species of Dicotyledons have been discovered in the Neocomian. In the lower part of the Cretaceous (including the equivalents of the Gault, Upper Greensand, and Chalk Marl of this country) the number rises to 357. "Thus we have a great and sudden inswarming of the higher plants of modern types at the close of the Neocomian." From that period the vege-

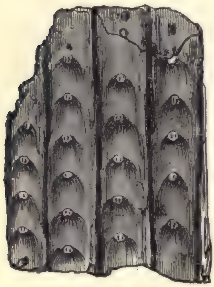


FIG. 148.
SIGILLARIA LÆVIGATA.

* Dawson, "Geological History of Plants," ch. v.

tation, the remains of which are often abundant, gradually draws nearer to that which still exists, indicating the same distribution into zones related to temperature as at present, but bearing testimony to very remarkable mutations of climate, to which reference will be made in a later chapter. For the present it may suffice to say that this flora indicates a gradual change from a climate not very different from that which at present prevails in the neighborhood of London to one in the Middle Eocene, when it was more like that now characteristic of Northern Africa. This was followed by a gradual refrigeration, until a considerable part of Britain was buried beneath snow and ice and the vegetation of the remainder was distinctly arctic in character. From this, the so-called Glacial epoch, the climate has gradually improved up to the present time.

Thus the botanical history of the earth comprises three great eras, which, however, are not separated by any hard and fast lines; the first characterized by ferns and gigantic lycopods and horsetails; the second, in which cycads, conifers, and palms predominated; and the third, when the larger plants, as at the present time, were mostly dicotyledons; and this class, as a whole, was the most numerous. These great life-groups of plants, it should be noticed, are not in any chronological relation with the principal steps in the development of animal life.

This, as has been already said, did not actually begin with the Cambrian period, but any earlier remains are ill-preserved and rather uncertain in character. But low down in the oldest strata of that system—the Harlech group—fossils occur which can be identified with certainty, and these represent more than one class of the animal kingdom. The strata at St. David's have been more prolific than any other in the British Isles, though even there fossils are very far from abundant. Sponges, worms, crustaceans, brachiopods, and pteropods occur—in all, over thirty species. The Crustacea are represented by some creatures of small size, distantly related to the existing "water-fleas," and by trilobites. The latter is an extinct order, resembling in some respects the living king-crabs (*Limulus*), in others the members of the order *Isopoda*, to which the familiar woodlouse belongs. The body consisted of a series of segments, varying in number from two to twenty, with a solid tail and with a head formed of three pieces, more or less firmly fastened together, the whole being divided into three lobes, from which characteristic the name is taken. On the under side were about eight pairs of slender legs. A trilobite is commonly from about six

lines to a couple of inches long; some species, however, are very minute, while others exceed a foot in length. Curiously enough, a species of the largest known trilobite (*Paradoxides*—Fig. 132) and of the smallest (*Agnostus*) occur side by side in the Harlech group; but the oldest genus which hitherto has been detected, and now serves to indicate the lowest zone in the Cambrian system, is named *Olenellus* (Fig. 149). This as yet has not been discovered at St. David's, but it has been found in Shropshire and in the Northwest Highlands, as well as in several localities out of England. The genus *Paradoxides* ranges through the remainder of the Harlech and the Menevian, and is succeeded by *Olenus* in the Lingula Flags. Though the fauna of the Harlech group, comparatively speaking, is a poor one, the dawn of life cannot have been very recent, for too many classes are represented, and too high a stage of development has been reached.

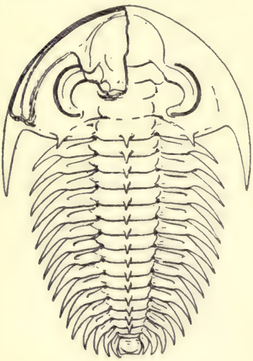


FIG. 149.
RESTORATION OF OLENELLUS.

Henceforth the fauna increases in number and variety, though, of course, a page may occur here and there in the record which is either a blank or nearly so; at any rate, in particular localities. The Menevian fauna runs up to fifty-two species, of which more than one-half are trilobites. A new class—the echinodermata—is represented by a cystidean.* The Lingula Flags are frequently rich in individuals. For instance, slabs of the rock are often thickly spotted with the remains of the little brachiopod (*Lingulella davisii*) from which the group was named;† but the number of species is not materially altered. A new class is represented by the net-like fossil *Dictyonema*, but whether this be a hydrozoan or a polyzoan is not quite certain. The opinion of experts now inclines to the former view. A new order of the Crustacea, the *Phyllopoda*, is represented. In the Tremadoc group the number of species increases to eighty-six. The orders already mentioned are represented, but, in addi-

* The *Cystidea* are an order bearing some likeness to the living Crinoids (sea-lilies) and Echinids (sea-urchins). They were never very abundant, and became extinct in the Carboniferous period.

† It was then considered to be a true *Lingula*.

tion, more than one new form of importance appears. Among the Hydrozoa two genera occur as the forerunners of the graptolites, an order which becomes of great importance in Ordovician times. Among the echinoderms the first "sea-lily" (*Dendrocrinus*) and the first "starfish" (*Palæasterina*) appear, and the lower parts of the Tremadoc have furnished the first heteropod, a "univalve," and the first lamellibranch or ordinary bivalve mollusk. The former class is represented by the genus *Bellerophon*, the latter by no less than five genera and twelve species, many of them belonging to the existing family of the *Arcadæ* or ark-shells. Here also are the first cephalopods. Two genera have been found, one of which (*Orthoceras*) survived even into Secondary times.

As already stated, the Tremadoc group has been included by some writers with the Ordovician, but it is by no means clear that the change is an improvement. According to Mr. R. Etheridge "no less than forty genera make their first appearance in the Arenig rocks in the British Islands." At the time when he wrote (1881) the total fauna of the group comprised 150 species. Of these only sixteen have come up from the Tremadoc group, and nine pass up into the overlying Llandeilo group. It is therefore curiously distinct as a fauna; and so far as percentage of species goes, the Tremadoc group is a little more closely attached to it than it is to the overlying Llandeilo; nevertheless the marked change exhibited by the Arenig fauna and the incoming of forms abundant throughout the Ordovician indicate that much may be said in favor of the earlier arrangement. The most remarkable feature in the Arenig fauna is the abundance of graptolites, which formerly were supposed not to occur in any earlier deposits. This, as stated above, is now known to be an incorrect view, but, after all, only the precursors of the order arrived in the later part of the Tremadoc. The graptolites form an extinct order of the Hydrozoa, which had a certain resemblance to the living sertularians, represented by the "sea-firs" common on the British coasts. The solid part (see Fig. 150) consisted of a chitinous material, and formed a hollow tube (*b*), strengthened by a

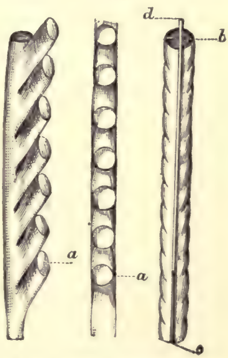


FIG. 150.—STRUCTURE OF A GRAPTOLITE.

rod or axis ($c\ d$), and communicating with a series of cups ($a\ a$), in which the individual polyps were lodged. Both single and branched forms occur, exhibiting considerable variety, and the cups are sometimes arranged on one side of the axis, sometimes on both, the latter being almost restricted to the Ordovician rocks, in which also a form occurs having four rows of cups set crosswise. Graptolites are supposed to have traveled to this country from America, as the number of genera and species is larger there, while it is smaller in Scandinavia and in Bohemia than in Britain. Trilobites continue to increase in number, and genera now make their appearance which have a long range in time. Brachiopods become more numerous, but the lamellibranchs are still very few. Gasteropods, however, or ordinary univalve mollusks, are now first found, four species being known; two of them belonging to the genera *Euomphalus* and *Pleurotomaria*, which afterward become rather common, and last for a long time.

In the Llandeilo group corals first appear. They are represented by three genera * and as many species, one of them being the familiar chain coral (*Halysites catenulatus*). Graptolites are plentiful, but the echinoderms are as yet very scanty. Brachiopods are becoming more numerous, for thirty-four species are found, but the mollusks are still only slightly represented. The whole Llandeilo fauna consists of 175 species, and forty-seven of the genera are new.

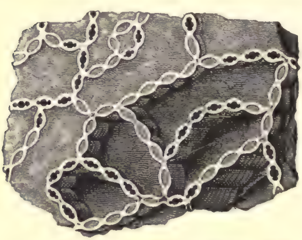


FIG. 151.—HALYSITES CATENULATUS.

The Caradoc or Bala fauna is a rich one, numbering 614 species, the classes most strongly represented being the Crustacea (146 species) and the Brachiopoda (109 species). The former are mostly trilobites, this order now attaining its maximum. There is a marked

* The older classification is followed in which the corals are divided into the orders *Rugosa*, *Tabulata*, *Aporosa*, and *Perforata*. The *Rugosa* had the *septa* (or calcareous plates in the interior of the "cup") arranged in multiples of four, while in the other orders they were developed in multiples of six. This classification is now much broken up. The tabulate corals (in which the cup was crossed horizontally by well-marked floors) are very widely dispersed, many being now relegated to the Hydrozoa. To this order *Halysites*, *Favosites*, and *Monticulipora*, the three genera above mentioned, belonged; so the statement now may be not strictly correct. But the classification, if artificial, was very convenient, so that it may be retained for purposes of general description.

increase in all the orders of the Mollusca, and chiefly in the lamellibranchs, which have now run up to 76 species, being more abundant here than in any other formation below the Carboniferous Limestone. There are 53 species of gasteropods and 47 of cephalopods. The graptolites continue numerous, and corals are now fairly common. Altogether the fauna of this system is rich not only in genera and species, but also in individuals, for the blocks of stone are often crowded with fossils.

The fauna of the Lower Llandovery, as might be expected from a time of transition and disturbance, is less rich than that of the Bala or Caradoc. It consists of only 204 species, or about one-third the number of the preceding formation, and exhibits no characteristic which calls for special notice. The Upper Llandovery fauna is somewhat richer than it in species, for these number 261. The Lower Llandovery receives slightly more than half its fauna (105 species) from the Bala, and transmits almost exactly the same proportion (104 species) to the Upper Llandovery. This accordingly consists of about two-fifths of the older fauna and three-fifths of its own. In the Lower Llandovery the lamellibranchs are few in number, but corals, crustacea, and brachiopods are fairly abundant. In the Upper Llandovery the Mollusca generally are better represented; the corals are increasing, but the trilobites are now beginning to diminish in the number of genera and species. Here, however, another peculiar class of the Crustacea makes its appearance, that of the *Merostomata*. This is divided into two orders: one, the *Xiphosura* (" sword-tails," from the long spike which terminates the carapace), is still represented by the living king-crabs. This, however, does not appear till the Carboniferous system is reached. The other, the *Eurypterida*, is first represented by the genus *Pterygotus* in the Upper Llandovery.* The above figure (Fig. 152) will give

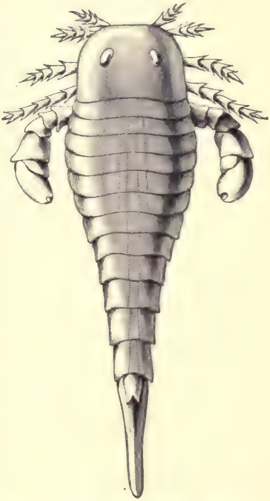


FIG. 152.—EURYPTERUS REMIPES.

* In Bohemia they have been found in beds of Ordovician age.

an idea of the general appearance of these creatures, some of which had a superficial resemblance to the macrurous (long-tailed) crustacea, such as the lobster; but from these they differed in more than one respect, perhaps the most marked being that in the latter the masticating organs are aborted legs, and these are followed by the appendages for locomotion, while in the *Merostomata* the same limb discharges both functions. In the Upper Llandovery also the first Echinids appear. These, however, like all the Palæozoic forms, differ from the existing sea-urchins in one important respect, that the test or "shell" is composed of more than twenty rows of plates; it was, moreover, commonly flexible, a character which has been very exceptional since that era. Both these newly come groups continue to be rare for a considerable time.

The Wenlock group has a rich fauna, consisting of 536 species. This may be partly due to the fact that it contains some rather important beds of limestone. Corals, both tabulate and rugose, are common, and form small reefs; so, too, are polyzoa, but graptolites are dwindling. Representatives of a singular group of Hydrozoa, called Stromatoporids, also occur, the true position of which was for long uncertain. The calcareous "skeleton," at first sight, resembled in some respects a foraminifer, in others a sponge, and in others a coral, and in general aspect recalled the noted *Eozoon*, which has been already mentioned (p. 347). They occur elsewhere in the Silurian, but are rather common in the Wenlock beds. Crinoids are numerous, at least twenty new genera making their appearance. This suggests a migration of the order, which, according to Mr. Etheridge, was probably from the west. Trilobites are abundant individually, but the number of species has diminished. The Merostomata are increasing, brachiopods are abundant, but the same can hardly be said of any of the true mollusca,* though certain genera, such as *Euomphalus* are far from rare. The fauna of the Ludlow group is less rich than that of the Wenlock, for it numbers only 392 species. Crustaceans, brachiopods, and lamellibranchs are the most abundant members. The graptolites have now almost disappeared, and the corals, as might be expected from the nature of the deposits, are not common. But the Ludlow beds exhibit one marked advance in the development of life, for in them the first vertebrate animals

* Although superficially the Brachiopoda seem to be very closely allied with the Mollusca, and are generally included with these in a manual on that subject, zoölogists consider them more nearly related to the Polyzoa, and class them with these in a separate subkingdom.

have been found. These are fishes, the oldest of them occurring in the Lower Ludlow stage. This, which is named *Scaphaspis ludensis*, belongs to the order of the ganoids—fishes which frequently were armor-plated; that is, protected by hard bony scales, some-

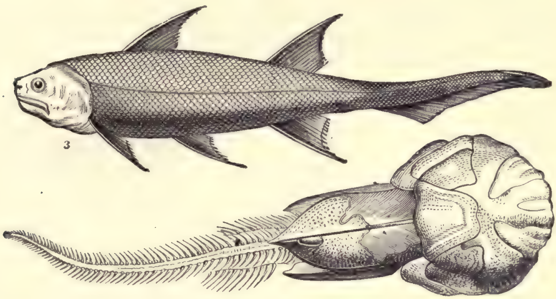


FIG. 153.—GANOID FISHES (OLD RED SANDSTONE).
The lower one (*Coccosteus decipiens*) shows the armor plating and skeleton only.

times covering the whole body. The members of this order predominated in the world until Cretaceous times, when they began to wane, and are now very scantily and sparsely represented, the most familiar form being the garpike (*Lepidosteus*) of the North American rivers. The Elasmobranchs,* an order to which the modern sharks, dogfishes, sawfishes, and rays belong, also appear in the upper part of the Ludlow group.

The Devonian rocks in Britain do not exhibit a rich fauna. The marine or normal type only reaches the surface in the southwest of England. The abnormal Old Red Sandstone type, which covers a large area in these islands, is not generally rich in life, ganoid fishes and merostomatous crustaceans being the most abundant. In Ireland a fresh water bivalve—*Anodonta jukesii*, closely allied to the living *Anodon* or swan mussel—has been found in the upper part of the Old Red Sandstone. This is the first indubitable fresh-water bivalve. In Canada and the United States, strata of Devonian age, which are rich in plants, have also furnished the first air-breathing mollusk, *Strophites grandævus*, and a few genera of insects related to the May flies and dragon flies. The marine fauna of Britain con-

* All the older types of fish are "heterocercal"—that is, the backbone is prolonged into one lobe of the tail fin, which is larger than the other.

tains 557 species, very few of which have come up from the underlying Silurian, and rather more than one-twelfth (most of them belonging to the upper part of the Devonian) pass up into the Carboniferous system. In the limestones, corals—tabulate and rugose—are abundant, as may be seen in the so-called "Devonshire Marble." They appear sometimes to have formed small reefs. The genera correspond with those of the Silurian rather than of the

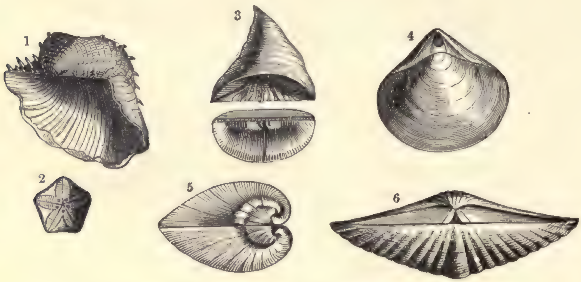


FIG. 154.—DEVONIAN AND CARBONIFEROUS FOSSILS.
(1) *Productus semireticulatus*; (2) *Pentremites florealis*; (3) *Calceola sandalina*; (4) *Stringocephalus burtini*; (5) *Megalodon cucullatus*; (6) *Spirifer speciosus*.

Carboniferous strata, but the species are usually distinct. A very peculiar solitary form called *Calceola sandalina* for long perplexed palæontologists. It was doubtfully referred to the brachiopods, but is now recognized as a rugose coral, which possesses an operculum, a very rare appendage. Stromatoporids also are rather common, but the graptolites have now all but disappeared. None have been found in the British Devonian rocks, properly so called, but one species has occurred in a bed of dark shale intercalated in the Lower Old Red Sandstone of Scotland. Of the Echinoderms, crinoids are fairly common, cystideans are declining, and an allied but equally unsuccessful order, the *Blastoidea*, makes its appearance. Trilobites are distinctly diminishing, but the Merostomata are comparatively common, and attain a large size; one genus, *Pterygotus*, sometimes grows to a length of six feet. Brachiopods are very abundant, the genus *Spirifera*, with its long hinge, being in great force. Some forms, which present a general resemblance to the living *Terebratula* (the lamp-shell) are very characteristic of the Devonian rocks; one of the commonest is the genus *Stringocephalus*, which, as the name (owl-head) implies, is distinguished from a true

Terebratula by the beak coming to a point instead of being truncated and terminating in a hole. One brachiopod, *Atrypa reticularis*, which swarms in the Wenlock Limestone, runs all through the Devonian strata. The geographical range of this shell is commensurate with its geological, for it has been found in almost every quarter of the globe. The different classes of the Mollusca are fairly represented, and the presence of coiled forms of cephalopods, with characteristics premonitory of the Secondary Ammonites (see p. 435), is interesting. As a whole, however, the fauna of this period does not show any very marked step in advance, and it clearly occupies a position intermediate between those of the Silurian and the Carboniferous systems.

In Great Britain, as already stated, the Carboniferous system in its lower portion is mainly represented by strata distinctly marine; in its upper almost wholly by beds of fresh water origin; but it must be remembered that this arrangement, after all, is a local accident, though it happens to hold good in most of the regions which, so far, have been more thoroughly examined. The marine fauna is a rich one. Foraminifera, hitherto rare, are now rather common, and sponges become much more abundant than in any previous formation. The Hydrozoa are not strongly represented, but rugose and tabulate corals are very frequent, making small reefs, the genus *Lithostrotion* being one of the most abundant of the former. Crinoids are also common; the number of species is somewhat large, but, as individuals, they must have occurred in swarms. Some of the so-called Derbyshire marble is crowded with portions of the stems, with detached plates from the bodies and fragments of the arms. These often belong to one genus, *Actinocrinus*. The variety of chert, locally called screwstone, is full of casts of these stems, the calcareous part of the organism having been removed from the siliceous matter by the action of water. The Crustacea have several representatives, though the trilobites are all but gone, only three genera, with but few species, now remaining. Eurypterids continue, and relations of the king-crab appear. Polyzoa are common, brachiopods are very abundant, the richest genera being *Spirifera* and *Productus*. The latter, which makes its appearance in the Devonian, swarms in the Carboniferous Limestone, one species, *P. giganteus*, sometimes measuring about twelve inches in its longest diameter; another species, *P. semireticulatus*, which also occurs very abundantly, is almost world-wide in its distribution. Blocks of the Carboniferous Limestone are often largely composed of the

shells of the one or the other species. The lamellibranchs are very abundant, more than 330 species occurring in the British Carboniferous Limestone alone. Gasteropods and cephalopods are also numerous, and though neither the pteropods nor the heteropods are represented by very many species, the genus *Conularia* in the former and *Bellerophon* in the latter are both well developed. Fish were abundant in these ages, both in the seas and in the rivers, some of them attaining a considerable size.

Passing now to the more distinctively non-marine Carboniferous fauna, for which in Britain we must generally look rather to the upper part of the system, little bivalve crustacea, related to the living *Cypris*—still common in pools and slow streams—literally swarmed in the marshy waters, for masses of shale are often spotted all over with their tiny cases. Representatives of other orders are by no means unfrequent, but as these forms are less generally familiar, we pass them by. Decapod crustacea * (to which the crabs and lobsters belong) now make their appearance, but at present are rare. Scorpions and other members of the *Arachnida* have been found, together with *Myriapoda*, distinctly related to the existing centipedes, and insects were not unfrequent in the forests of this age. They present resemblances to more than one existing order, but are referred by Mr. Scudder, the chief authority on this subject, to "a single homogeneous group of generalized hexapods which should be separated from later types more by the lack of those special characteristics which are the property of existing orders than by any definite peculiarities of its own." † Some seem like forerunners of May flies, others of cockroaches, others, again, of beetles: the wings of one American specimen must have measured nearly seven inches across. The first representatives of the order appear on the Continent at an earlier date, low down in the Silurian rocks of Calvados; a few occur in the Devonian, and they become rather more common in the fresh-water or estuarine deposits of the Carboniferous system. Fresh-water bivalves are sometimes very abundant, several of the genera being rather nearly related to the living river mussel (*Unio*). On turning to the verte-

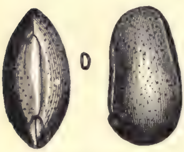


FIG. 155.—CYPRIS.

* In America they have occurred in Devonian rocks.

† Nicholson and Lydekker, "Manual of Palæontology," vol. i. p. 592.

brates we find that fish swarmed; but a great step is now taken, and representatives of a higher class, the Amphibia, make their appearance. All belong to one order, the Labyrinthodonts, so called from the curiously convoluted or labyrinthic structure exhibited by their teeth. This peculiar dental structure is also found in some of the ganoid fishes, to which this order in other respects is allied. Altogether 26 species, belonging to 21 genera, have been identified in the British Isles. Amphibians also occur in other parts of the world in beds of the same age, and in Nova Scotia the body of one form (*Dendrerpeton acadianum*), about three feet long, was found coiled up in the sand which had filled the hollow trunk of a Sigillarian tree. No true reptiles have as yet been identified with certainty, although a little doubt exists as to the proper zoölogical position of one form; all probably belong to the Amphibia.

The fauna of the Permian system in Britain is comparatively poor and stunted, and is indicative of somewhat exceptional conditions, possibly those of an inland sea, like the Caspian, or of one which communicated with the open ocean by a rather narrow strait, like the Black Sea. It has a closer relationship, on the whole, with the fauna of the Carboniferous system than with that of the Trias. Sponges, foraminifers, corals, echinids, annelids, and crustacea are but poorly represented. No trilobite has been discovered in any British deposit of this age, the last having been found in a bed in the Millstone Grit, but one genus (*Phillipsia*) has occurred in the Permian deposits of Russia and of North America. Polyzoa are sometimes numerous, and brachiopods fairly represented; so also are lamellibranchs and gasteropods, but both the pteropods and the cephalopods contribute only a single genus each. Some fishes and amphibians are found, and the first indubitable reptile (*Proterosaurus*) makes its appearance. In other parts of the world a much richer fauna characterizes the Permian deposits, as, for instance, in Russia, the Southeastern Alps, Sicily, and in parts of Asia and North America. It exhibits distinctly a transitional character. Not a few well-known Carboniferous forms, such as the foraminifer *Fusulina*, the brachiopods *Productus*, *Orthis*, *Leptæna*, and other well-known Primary genera, are common, together with species of *Bellerophon*, and such cephalopods as *Orthoceras*, but among the lamellibranchs several genera of a newer type appear, and cephalopods closely allied to the Secondary Ammonites occur frequently in the Asiatic Permians.

Casting a retrospective glance over the fauna of the Primary or Palæozoic era, we find that, practically, all the more important classes and orders from the Reptilia downward are represented, and that the latter evidently are coming upon the scene as the era is drawing near to its close. We also notice that the development of life exhibits a gradual and fairly uniform progress, and that the earlier forms of any class or order are more generalized than those most nearly allied to the species which are still in existence; that is to say, they in one unite characters which are now exhibited by separate types, and thus often resemble more closely the embryonic than the adult forms of creatures which are now living. The imperfection of the data on which inferences are grounded must never be forgotten; the idea of an extinct flora or fauna in many cases has to be obtained from comparatively limited areas, in which deposits may have occurred, as with the Coal Measures or the Old Red Sandstones, under rather exceptional conditions. Still, even if every allowance be made for such difficulties, the absence of some of the more highly developed forms of life from these ancient deposits may be regarded as a certainty, and the proportion among those which did exist was very different from that now prevalent in the globe. Restricting ourselves to the fauna only, we may venture to affirm that there were neither birds nor mammals; amphibia were not common; reptiles only just beginning their career; and the fishes mostly belong to orders which since then have dwindled or have become extinct. Certain abnormal hydrozoa and corals referred to the rugose and tabulate orders took the place of those which now tenant the warmer seas. Crinoids were more common than sea-urchins and starfishes; trilobites are found instead of crabs, lobsters, and shrimps. Until the Carboniferous period none of the true mollusca were very abundant, the brachiopods taking their place. Some of the orders, most of the genera, all the species of the Primary era have now disappeared.

The changes foreshadowed in the Permian are carried much further in the Trias. On this subject the British Islands supply but little information to the geologist. The Bunter group is probably destitute of fossils; the Keuper contains but few; the Rhætic beds are thin, and far from rich in organic remains. But the gap in our knowledge, due to the abnormal conditions which have been already mentioned,* is filled up in other countries. The marine

* Pp. 370–378.

beds (*muschelkalk*) intercalated between the Bunter and the Keuper in Lorraine, Alsace, and the adjacent parts of Germany contain a fair number of fossils, but the Trias of the Eastern Alps is altogether a marine series, and is much richer in organic remains. Beds of this type may be traced, not only throughout the Mediterranean area, but also in various parts of Asia, America, and even in New Zealand and Australasia. In these neither foraminifers nor sponges can be called very common. Certain crinoids are rather numerous, such as the genus *Encrinus*, but the characteristic Palæozoic types have disappeared. Echinoids of the normal aspect now begin to be frequently found, among them the genus *Cidaris*, which still exists in the warmer seas, though a few of the peculiar older forms yet linger. Brachiopods are relatively less numerous than heretofore; the Palæozoic forms are either dwindling or have already gone; the genera *Terebratula* and *Rhynchonella*, which have been long in existence and still survive, now assume a greater importance. The lamellibranchs, however, appear to be elbowing these humbler bivalves out of the way. Many genera, very characteristic of the Secondary rocks—some extinct, as *Monotis*, *Halobia*, and *Gervillia;* others still living, such as *Pecten*, *Lima*, and *Cardita*—are now abundant, and give a marked character to the fossils of this period. Gasteropods also are plentiful, showing a mixture of old and new types; so too are cephalopods. The Palæozoic *Orthoceras* brings its long career to an end; Nautilus continues, but the most interesting forms are the representatives of the Ammonites. The transitional *Ceratites*, with its peculiar sutures exhibiting alternating saddles and lobes slightly denticulated (see Fig. 145 *b*), practically characterizes the Trias, and is the immediate forerunner of the great family of the Ammonites, which, as already mentioned, swarm in many of the Secondary rocks; of these also a few actual representatives are found in Triassic strata. Fish are fairly numerous, and among them "the oldest representatives of the bony fishes, or *Teleostei*, which is now the most predominant group," probably occur. Amphibia seem to have been rather abundant, and some of the Labyrinthodonts attained a large size, being, perhaps, seven or eight feet in length. Their footprints are not uncommon on some of the flaggy sandstones in various parts of England.* Certain of these present a rude resemblance to the mark of a gigantic human hand, whence the name *Cheirotherium* (hand-beast) was formerly given (Fig. 135).

* Especially in Cheshire and the adjoining counties.

These tracks, however, and the animals which made them, have not as yet been coupled together with any certainty, and it is possible that some may be the imprints of true reptiles. These "were very abundant in the Trias, especially in comparison with the Permian. Almost all the groups characteristic of Mesozoic times had their representatives in the Trias." * But as they do not become common in England till the next period, it will be more convenient to abstain, for the present, from entering into details. Certain tracks in the Triassic sandstones of Connecticut, which formerly were supposed to have been made by birds, are now referred to reptiles. But though the existence of the former in Triassic times has not yet been established, the occurrence of mammals cannot be questioned; these have occurred higher up in the Keuper—both in the neighborhood of Stuttgart and in Somersetshire; others have been found in beds, presumably of the same age, in North Carolina and in South Africa; mammalian remains also have been occasionally met with in beds of Rhætic age in England and in other countries. All these earlier forms were "of small size, and apparently more or less closely allied to the existing marsupials, and probably also to the monotremes, and perhaps the insectivores." † The Anglo-German form *Microlestes* (little thief) was a small predaceous creature, the exact relationships of which are uncertain, for at present it is known only by its teeth. The South African *Dromatherium* (running beast) was larger. As this "exhibits some curious approximations in the structure of its teeth to reptiles and amphibians," it may be an ancestral type of the mammals.

The Jurassic rocks, both in Britain and in the western parts of Europe, exhibit a great variety of materials, and contain abundant remains of a flora and a fauna. The deposits, though on the whole marine, were in many cases formed in the vicinity of the land, and occasionally indicate a terrestrial origin. On this account the fauna exhibits corresponding variations; no one would expect to meet with a coral reef in a clay bed, or river mussels in a deep-sea limestone. But as our space is limited, we must speak of it as a whole, without dwelling on details or separately describing the tenants of

* Kayser and Lake, "Text-book of Comparative Geology," p. 233.

† Nicholson and Lydekker, "Manual of Palæontology," ch. lviii. The monotremes are a very low type of mammals, obtaining the name from the fact that the urine and the fæces are discharged by a single outlet. The *Ornithorhynchus* or duck-billed platypus of Australia is one of the few living representatives of the order. The marsupials (pouched animals) are represented by the kangaroos and opossums; the moles and shrews belong to the insectivores.

the land and of the sea. Foraminifera are not rare; sponges are often common; corals are sometimes very abundant; they belong chiefly to the aporose division, several of them being more or less nearly allied to the star-coral and brain-coral of the present day, for the old tabulata and rugosa have disappeared; they occasionally

FIG. 156.—PENTACRINUS BRIAREUS (EXTRACRINUS).
a, Reduced in size. b, Body and parts of arms, natural size.

form reefs, but some smaller solitary corals are also frequent. Sea-urchins abound; most of them belong to extinct genera, but all possess the usual twenty rows of plates, and represent both the regular group (more or less circular in form) and the irregular group (often heart- or shield-shaped); a few, however—as, for instance, *Cidaris*—still exist on the earth. Sea-lilies are less abundant on the whole, though the beautiful *Pentacrinus* (Fig. 156)—a genus which

still lives—seems to have swarmed in some localities on the sea bottom during the earlier part of the Liassic epoch—for often a dozen specimens may be counted on the surface of a slab considerably less than a square foot in area. In this, as in a large number of the more modern crinoids, the joints of the stem are pentangular in outline; but forms with a rounded stem, like the Palæozoic crinoids, are also found, as, for instance, *Apiocrinus* (Fig. 157), which is rather abundant at a somewhat later time, about the middle of the Lower Oolite. The crustacean fauna includes both long-tailed and short-tailed members, and this, as well as the insect fauna, is fairly rich. A very marked change has passed over the brachiopods. The characteristic Palæozoic genera, such as *Orthis*, *Atrypa*, *Pentamerus*, *Productus*, etc., have disappeared; *Leptæna* and *Spirifera* struggle on into the lower part of the Jurassic system and then vanish. *Rhynchonella* and *Terebratula*, with a group of genera closely allied to it, dominate over all the others, being represented by many species and by swarms of individuals. The lamellibranchs have now obtained the footing in the world which they have kept ever since—genera, species, individuals, all are numerous. Many genera, which are still abundant, had already risen to a great importance, such as *Ostrea* (the oyster), with several of its allies, as *Gryphæa* and *Exogyra*, also *Lima*, *Pecten* (fanshell), *Avicula*,* *Gervillia* (extinct), and *Trigonia*. Genera allied to the living *Anatina* (lantern-shell), such as the existing *Pholadomya*, and the extinct *Ceromya*, *Goniomya*, and *Myacites*, are frequent in the more calcareous rocks. The gasteropods also are richly represented: among the most characteristic are trochus-like shells, such as *Pleurotomaria* (extinct), and elongated spiral shells, which take the general

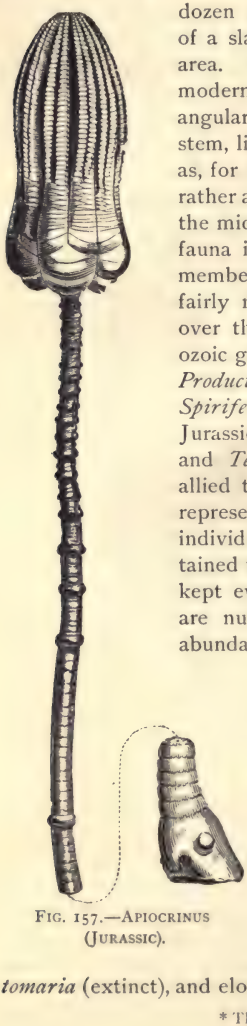


FIG. 157.—APIOCRINUS (JURASSIC).

* The "pearl-oyster" is an *Avicula*.

outline of the living *Turritella* (cockspur), such as *Cerithium*, *Chemnitzia*, *Nerinea*, with its curious internal ridges, which render the genus so easy of recognition; and winged shells, such as *Pteroceras* and *Alaria*, resembling the *Aporrhais* (bat's-wing), still found on British shores.

But the more marked characteristic of the Jurassic molluscan fauna is the abundance of representatives of the cephalpods. The one group, *Belemnites*,* is distantly related to the living cuttlefishes.

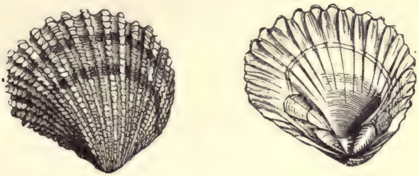


FIG. 158.—SHELL OF A TRIGONIA (RECENT).

The genus, which makes its appearance in the continental Trias, abounds in strata of Jurassic age. The number of individuals must have been very great. The shells sometimes lie in layers, so that the bed of the sea must have been strewn with them. The other group is that included in the old genus *Ammonites*. Members of this occur in even greater profusion than the belemnites; the different species vary greatly in size: more commonly they run from about four inches in diameter downward, but about double this is reached by a fair number of species, and a gigantic form is occasionally met with, measuring perhaps a couple of feet across. The nautilus keeps on the even tenor of its way, but these newcomers quite throw it into the shade in their brilliant but not very durable career.

But in the Jurassic period the vertebrate fauna becomes more important than it hitherto has been. The fish still continue to be mainly ganoid, but as the older heterocercal forms have almost disappeared, they present a closer resemblance to those which are now in existence. Mammals continue, but their remains are seldom

* The shell is long, somewhat conical, and pointed at one end; the other opens out into a wineglass shape and the lower part is partitioned off by septa. In this the more important organs of the body were lodged, and the shell, like that of the cuttlefish, was partly, if not wholly, internal. Commonly it does not exceed a few inches in length, but specimens measuring nearly three feet are known. Workmen sometimes call them thunderbolts.

found, and the representatives of this class appear not to have departed far from the original Triassic types, being small in size, and allied to the monotremes and marsupials of the present day. In England two or three have been found in the "Stonesfield slate," a local deposit underneath the Bath Oolitic Limestone, *i. e.*, about the middle of the Lower Oolite, and a larger number in the Purbeck beds, which are at the very top of the Jurassic system. Birds also make their appearance, though evidently not in great numbers. The earliest one known, called *Archæopteryx*, has occurred in a muddy limestone at Solenhofen, in Bavaria, of about the same age as the Kimeridge Clay of England. This most instructive form may be called a true bird, for "the feathers, the closed skull, and the structure of the foot are sufficient proof of this. The biconcave vertebræ, however, the sclerotic ring of the eye, the teeth, the long lizard-like tail, the very thin ribs, pointed at the end, the presence of twelve to thirteen pairs of abdominal ribs, the three free claw-bearing fingers of the anterior limb, etc., are characters which are partly of an embryonic nature, partly characteristic of reptiles, so that this remarkable animal bridges over in a great measure the large gap existing at present between birds and reptiles." *

But the most characteristic feature of the Jurassic rocks is the extraordinary development of the latter class. Reptiles occur no doubt sparsely in the British Trias. They are much more abundant in continental and foreign deposits, but with the commencement of the Jurassic period they became generally common, both on land and in sea. Chelonians (tortoises and turtles) increased in number, and so did representatives of the crocodiles, though these differed from existing genera in retaining some embryonic characteristics. But the most abundant reptiles in the earlier part of the Jurassic period were marine, *Ichthyosaurus* (fish-lizard) and *Plesiosaurus* (neighbor-lizard) being the most important genera; the former, a huge creature, sometimes more than thirty feet in length, with tremendous jaws armed with strong conical teeth, was powerfully built, as shown in the diagram (Fig. 159), and was propelled by four paddles and its strong tail, which was terminated by a broad triangular fin, like that of a fish, into the lower lobe of which the backbone appears to have been prolonged. The creature in general shape slightly resembled a whale, and was an air breather, but it had a

* Kayser and Lake's "Text-book of Comparative Geology," p. 278. Two specimens have as yet been found—one is in the British Museum, the other (and more perfect) is that at Berlin.

dorsal fin, like a fish. It appears, however, to have been viviparous, for in one case the skeletons of seven very small *Ichthyosauri*, all of the same size, were discovered within that of a large one. The eye was large, and fitted with an arrangement of bony plates, the presence of which probably not only protected the eye from pressure in deeper water, but also served to modify the curvature of the lens and to adjust the focus for seeing near or distant objects. The *Plesiosaurus* had a much smaller head, furnished with sharp but less formidable teeth, placed above a long neck. The tail was shorter and the paddles were more slender than in *Ichthyosaurus*. It was a less powerful animal than this, but its lithe neck, pliable as that of a swan, must have enabled it to grope after its prey in the shallower waters, or to strike readily in all directions as it swam swiftly along, while the *Ichthyosaurus* probably dashed like a shark at its victim. We can imagine a shoal of the scaly ganoid fishes scattering before its charge, like roach from the rush of a pike at the present day. There were, however, other tyrants of the seas more formidable than the *Ichthyosaurus*, but apparently much less common; these belong rather to the later part of the Jurassic. One of them, the genus *Pliosaurus* (more nearly a lizard), must have been a huge creature, for the jaw is nearly six feet long, with pointed teeth measuring three or four inches.

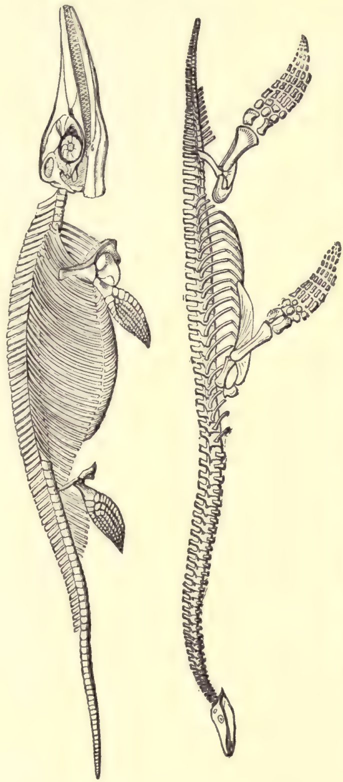


FIG. 159.—SKELETONS OF ICHTHYOSAURUS AND PLESIOSAURUS (RESTORED).

Another important order of reptiles, that of the Dinosaurs, rapidly increases in importance during the Jurassic period. These were sometimes terrestrial, sometimes semi-aquatic, and many of them attained to a huge size. The European forms are remarkable enough, but America has furnished types yet more singular and gigantic. The limbs, as a rule, are longer and stronger than in modern lizards. One group, which attains to a greater size than the other, had a long tail and neck, with a head, on the whole, relatively small, while the proportions of the middle part of the body were not very different from those of an ordinary mammal. In the other group the neck was shorter and the head somewhat larger, while the fore limbs were considerably smaller than the hind legs, so that probably the creature frequently sat up like a kangaroo, and may even have hopped along in the same way. Of the former group the largest English representative is the *Cetiosaurus* (whale-lizard), which probably was about fifty feet in length, and must have stood about ten feet in height, for the thigh bone occasionally is nearly five feet long.* But its American allies *Brontosaurus* (thunder-lizard) and *Atlantosaurus* (Atlantic-lizard) were on a yet vaster scale, for a thigh bone of the latter has been discovered which is a little over six feet in length. *Brontosaurus* was not quite so huge, but "it was nearly sixty feet long, and probably when alive weighed more than twenty tons. That it was a stupid, slow-moving reptile may be inferred from its very small brain and slender spinal cord. . . No bony plates or spines have been discovered with the remains of this monster, so that we are driven to conclude that it was wholly without armor; and, moreover, there seem to be no signs of offensive weapons of any kind. Professor Marsh concludes that it was more or less amphibious in its habits, and that it fed upon aquatic plants and other succulent vegetation. Its remains, he says, are generally found in localities where the animal had evidently become mired, just as cattle at the present day sometimes become hopelessly fixed in a swampy place on the margin of a lake or river. Each track made by the creature in walking occupied one square yard in extent." †

* Found in the upper part of the Lower Oolite. Phillips' "Geology of Oxford," ch. xi.

† Quoted from Mr. H. N. Hutchinson's "Extinct Monsters," p. 64, where a figure of the skeleton and a restoration of the creature is given. This pleasantly written volume gives a very good account, founded on the works of Professors O. C. Marsh, E. D. Cope, Owen, and other authorities, of the monstrous vertebrates of olden time, with some excellent pictures of their probable appearance.

Of the other group of the Dinosaurs some were herbivorous, some carnivorous. The former are represented in England by more than one form, the earliest being *Scelidosaurus* (leg-lizard)* from the Lias. It was probably amphibious in habit, not less than twelve feet long, and distinguished by carrying "two big spines, one placed on each shoulder, and a series of long plates, arranged in lines along the back and side." Stranger still is *Stegosaurus* (roof-lizard), of which some fragmentary remains have occurred in the Upper Oolite of this country, but far more complete materials have been obtained in America, from which Professor Marsh has been able to give a complete restoration of this singular animal. It had a remarkably small head and short neck, with the usual large hind legs and long tail. On the middle of the back, from immediately behind the head, and continuing to rather more than halfway down the tail, it bore a practically continuous row of bony plates, which, toward the middle, became pentagonal or rudely triangular in outline, and attained a diameter of from two to three feet. When these came to an end their place was taken by four pairs of strong spines, the first of which was quite two feet long. *Stegosaurus* exhibits another most singular characteristic. This is "a large chamber in the sacrum,† formed by an enlargement of the spinal cord. The chamber strongly resembled the brain-case in the skull, but was about ten times as large. So this anomalous monster had two sets of brains, one in its skull and the other in the region of its haunches! and the latter, in directing the movements of the huge hind limbs and tail, did a large share of the work."‡ Perhaps the favorite method of scholastic stimulation adopted by educationalists of the type of Busby was an unconscious recognition of the possible survival of some such structure in immature humanity. In the great doctor's day not a few schoolboys would have been thankful for the protective armor of *Stegosaurus*.

Carnivorous Dinosaurs are represented by the formidable *Megalosaurus* (great-lizard). Its remains occur throughout the Jurassic rocks from the Lias upward, and it survived that period.§ It had one element of a long existence, in days when the weakest went to the wall, for it was well able to take care of itself. In length it attained

* So named by Professor Owen because of its strong hind legs.

† The vertebræ (usually joined together) which are united with the haunch bones to form the pelvis.

‡ H. N. Hutchinson, "Extinct Monsters," p. 104.

§ Its form had a general resemblance to that of *Iguanodon*. (See Fig. 162, p. 467).

about thirty feet; it had strong hind limbs, formidable claws to its feet, and jaws furnished with long, conical, slightly curved teeth. It probably was an active animal, as terrible on land as the Ichthyosaurus in the sea. No wonder the mammals continued small and lowly in organization so long as these ferocious brutes existed! But "such small deer" can hardly have satisfied them; very likely the younger herbivorous Dinosaurs had to keep a sharp lookout, and cannibalism may not have been unknown, when other food was scarce.

The structure of the Dinosaurs is anomalous in more than one respect, and the precise position of the order in the animal kingdom is not easily determined. Of the little *Compsognathus* (elegant-jaws), from the Lithographic Stone of Solenhofen (Upper Oolite), Professor Huxley remarks: "It is impossible to look at the conformation of this strange reptile and to doubt that it hopped or walked in an erect or semi-erect position, after the manner of a bird, to which its long neck, slight head, and small anterior limbs must have given it an extraordinary resemblance." * The structure also of the bones in Dinosaurs frequently approximates to that of birds, and the skeleton exhibits other characters which are distinctly avian. Professor Huxley considers them as the progenitors of birds, and Professor H. G. Seeley, who has devoted many years to the study of the order, maintains that they cannot be regarded as reptiles in the ordinary sense of the term. Nevertheless in other respects they resemble the lizards and crocodiles, so that in them, as in so many other of these earlier creatures, characteristics are united which are now divided among widely separated forms of life. *Archæopteryx*, with its long tail and teeth, as well as some of the earlier birds, also dentigerous, undoubtedly suggest that their relationship with the Dinosaurs is far from being distant.

Flying dragons are common in legendary lore; cockatrices, griffins, wyverns figure in heraldry among "collections of fabulous animals." Yet creatures of the kind lived among the "dragons in the prime," though, strangely enough, they ceased to exist long ages before man appeared upon the earth. The Pterodactyles, or wing-fingered lizards, forming the order *Ornithosauria* (bird-lizards), are found in the Liassic rocks, and continue through the remainder of the Secondary series. They become more abundant in the later part of the Jurassic and the following systems, and as

* Quoted in "Extinct Monsters," p. 80.

they increase in number so do they, on the whole, in size. As to the latter, different members of the family vary greatly. Some were hardly bigger than sparrows, the wings of others had a span of about twenty-five feet. In many respects they resembled birds; the bones are often hollow; the breast bone has a keel; the skull

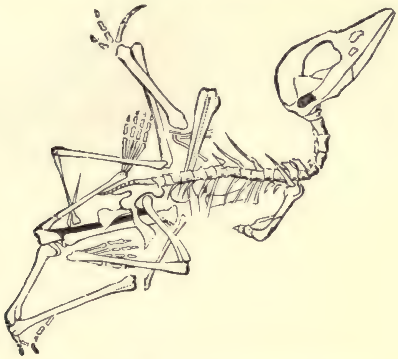


FIG. 160.—PTERODACTYLUS BREVIROSTRIS.

also, in the position of the nostrils, the character of the eye, and in other respects, suggests avian affinities. The jaws are long, powerful, and armed with sharp, flattish, slightly curved teeth; the fore limbs terminate in four fingers or toes, three being furnished with claws, and the other, or outer one, prolonged to a great length, to support a membranous wing, somewhat like that of a bat. This mammal, however, has five fingers, and four of them are elongated to carry the wing. The members of the Ornithosaurian order, as Mr. Lydekker truly observes, are among the most remarkable and strange reptilian forms that Palæontology has revealed to us. Some authorities, indeed, have proposed to place them in a distinct class. They are, however, in his opinion, essentially reptiles, and the resemblances, striking though they may be, are probably "mainly due to adaptation for a similar mode of life, since it seems clear that the Pterodactyles are altogether off the direct line of the avian pedigree."*

We have dwelt at some length on the Jurassic fauna, since it presents us in Britain with so many new and interesting types. But

* "Manual of Palæontology," p. 1198.

this enables us to pass more rapidly over the remainder of the Secondary series, and for that purpose to group together the Neocomian and Cretaceous systems, since their faunas have a general resemblance to each other, though they seem to differ sufficiently to justify a distinction by separate names. The English representatives, both of the one and of the other, are somewhat abnormal; for in the lower part of the former we find, in the southeast of England, the fresh-water deposits of the Weald, and in the upper and major part of the other the White Chalk, a very pure and rather deep-sea deposit.

The marine invertebrate fauna does not call for many remarks. As it departs gradually from the Jurassic facies, it approaches somewhat to that characteristic of the present age. Foraminifera are occasionally very abundant, as *Orbitolina* in the limestone of the Upper Neocomian in the Alps, and as in the Chalk of Northwestern Europe; sponges also are often very common, as, for instance, in the flint-bearing Chalk. The corals are not usually remarkable; reef-building forms may be found in the lower part of the Cretaceous in the Northeastern Alps; but those of the White Chalk are small and solitary. Crinoids and starfishes are not generally abundant, but echinoids are often numerous, and the irregular group is more largely developed than the regular one; in the Chalk the genera *Echinoconus*, *Echinocorys*, and *Micraster* are common.* The polyzoa are many. Among the brachiopods the genera *Terebratula* and *Rhynchonella* dominate, and are often very abundant. Some aberrant bivalves are the most interesting mollusca. One group consists of twisted forms allied to the living *Chama*, and to the older genus, casts of which present a rude resemblance to a pair of ram's horns (*Diceras*); in the other, a separate family, one valve is funnel-shaped, the other being like a lid. These are mainly Cretaceous, but are rather uncommon in England, though one genus (*Radiolites*) is not rare at the base of the Chalk in Cambridgeshire, and sometimes attains a length of full half a yard.† Another (*Hippurites*), also large, is very common in the limestones of Southwestern France. Belemnites are less abundant than formerly, and are chiefly represented by a sub-genus, *Belemnitella*, which is dis-

* The commonest species are *Echinoconus conicus* (*Galerites albogalerus*), *Echinocorys vulgaris* (*Ananchytes ovatus*), and *Micraster coranguinum*.

† Found in a stratum about a foot thick, rich in phosphatic nodules, called the Cambridge Greensand, which is about the age of the very top of the Upper Greensand, and contains many fossils washed out of the Gault.

tinguished by a slit on the side of the "guard." Ammonites are still fairly common, and the allied forms, which no longer coil themselves in a plane-spiral, are much more abundant than they were in earlier times. The crustacea approximate more closely to the types of succeeding periods, and the little *Cypris* with allied genera again swarm in the fresh-water shales of the Wealden.

Among the vertebrates the "bony fishes" assume a greater

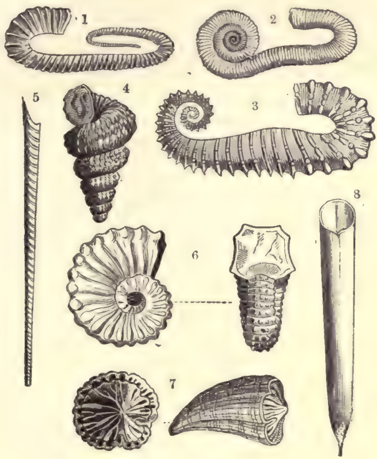


FIG. 161.—CRETACEOUS FOSSILS.

(1) *Hamites attenuatus*; (2) *Scaphites ivanii*; (3) *Ancyloceras matheronianus*; (4) *Turrilites bergeri*; (5) *Baculites anceps*; (6) *Ammonites (Acanthoceras) rothomagensis*; (7) *Hippurites cornuvaccinum*; (8) *Belemnitella mucronata*.

importance, but large sharks, armed with formidable teeth, must have been common in the seas. As representatives of the Reptiles, *Ichthyosaurus* and *Plesiosaurus* continue, and the place of the formidable *Pliosaurus* is occupied by the no less formidable *Polyptychodon*. The winged-lizards also are well represented, and attain on the whole to a larger size than in the Jurassic deposits, for here specimens with a span of wings amounting to as much as twenty-five feet have been found.* Chelonians were common in marshes, rivers, and seas, as well as crocodiles, and among the more peculiar of the Cretaceous reptiles were the gigantic snake-like *Pythono-*

* Nicholson and Lydekker, "Manual of Palæontology," p. 1201.

morpha. One genus, *Mosasaurus*, has been long known from the magnificent jaw discovered, in 1770 at Maestricht, in a yellow limestone which overlies the White Chalk.* A number of extraordinary and huge creatures belonging to the same order have been unearthed in Western North America, and reconstructed by Professor Cope and Professor Marsh.† Some were of huge size, one species attaining a length of seventy feet. The sea serpent of modern times is most probably a myth ; in the Cretaceous waters it was a reality.

The Dinosaurs still remain as "lords of creation." The predaceous *Megalosaurus* continues to flourish, but is joined by a creature somewhat similar in general form, but which must have been harmless, for it was an herbivorous animal—provided it did not lose its temper, when it could have made itself as objectionable as an hippopotamus or rhinoceros. This was the *Iguanodon*, first discovered in the sandstones of the Wealden in Sussex by the late Dr. Mantell, which was for some years a sore puzzle to the comparative anatomist of the last generation. For a considerable time the remains discovered were in a very fragmentary condition, but at the present probably no dinosaur is better known—at any rate, in Europe. This has been the result of a most singular discovery made in 1878 "in the colliery of Bernissart, in Belgium, between Mons and Tournai, near the French frontier. The coal-bearing rocks (Coal Measures) of this colliery, overlain by Chalk and other deposits of later age, are fissured in many places by deep valleys or chasms more than 218 yards deep. Though now filled up, they must at one time have been open gorges on an old land surface. Into one of these chasms were somehow precipitated [twenty-nine] iguanodons, numbers of fish, a frog-like animal, several species of turtles, crocodiles, and numerous ferns similar to those described by Mantell from the Weald."‡ At least five of these iguanodons are already separated from the matrix, pieced together, and exhibited in the museum at Brussels. The carcasses may have been swept down by floods, which are sometimes very destructive in the narrow ravines of districts liable to sudden and heavy rains ; or they may

* The specimen is now at Paris. An ecclesiastical corporation took it from the original discoverer under the form of law, and a French army took it from them by the right of war ; so that, on the whole, justice was done, except to the original discoverer, who got nothing but a lawsuit for his pains.

† Three forms are depicted in Plate XIII. of Mr. H. N. Hutchinson's book, "Extinct Monsters."

‡ H. N. Hutchinson's "Extinct Monsters," p. 91.

been mired if a boggy spot occurred unexpectedly at this place. The creature, as already said, was herbivorous, sat up on its hind legs, and perhaps progressed somewhat like a kangaroo; and the larger species (for there are two) measured rather more than thirty feet from the tip of the snout to the end of the tail, and could probably lift its head about half as many feet above the ground.

Hylæosaurus, so named by its discoverer, Dr. Mantell, because it was found at Tilgate forest on the Weald of Sussex, took the place of *Scelidosaurus*, and was possessed of an even better developed dermal armature. But the strangest creature of the Cretaceous period is the *Triceratops* (three-horn face) of America. It is one of the latest in date of the Dinosauria, for its remains are found in the Laramie beds, which, as already said (p. 329), occupy an intermediate position between the true Cretaceous and the true Eocene. The creature

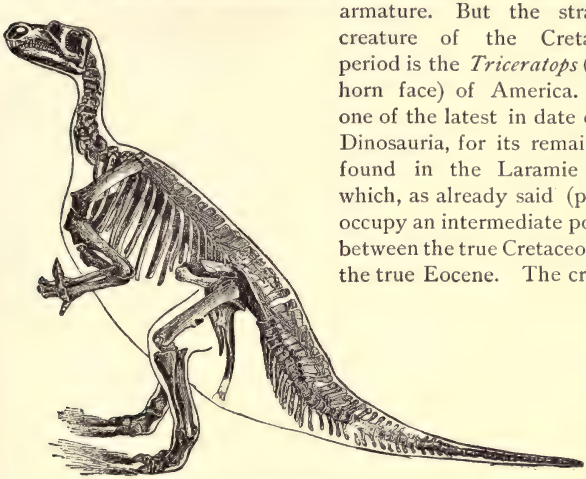


FIG. 162.—SKELETON OF IGUANODON.

when full grown was probably about twenty-five feet long, and the top of its back was full eleven feet from the ground. The skull was enormous—perhaps quite seven feet long, and of an extraordinary shape. Above the nose was a small horn, and a much larger one immediately over each eye; "the back part of the skull rises up into a kind of huge crest, and this during life was protected by a special fringe of bony plates." The mouth terminated in a kind of beak sheathed with horn, and the creature was probably provided with some sort of dermal armor. It cannot have been very intelligent, for "the brain was smaller in proportion to the skull than any known vertebrate." Professor Marsh thinks that "as the head increased in size to bear its armor of bony plates, the neck first, then

the fore feet, and then the whole skeleton was specially modified to support it"; but that at last the head became too heavy for the body to bear, and led to the extinction of the race; so that the epitaph on *Triceratops* might be: "I and my race died of over-specialization."*

No Cretaceous mammals have yet been described, though they have been recently found in America, and a tooth from the English Wealden is referred by Mr. Lydekker to this class. Doubtless they existed, but evidently were not yet important. Some scanty remains of birds have been described by Professor H. G. Seeley from the base of the Chalk of Cambridgeshire; but others, in better preservation from North America, have been the subject of a memoir by Professor Marsh. He describes twenty forms, and two of the genera are known to have been dentigerous. One *Ichthyornis* (fish-bird), with well-developed wings, was about as big as a rock pigeon; the other, *Hesperornis* (bird of the West), may have stood five or six feet high. It was unable to fly, and is compared by Professor Marsh to a swimming ostrich.

We conclude, then, that the Secondary era witnessed the beginning of Avian and Mammalian life, but that neither class was able to attain to importance. They appear to have been few in number, generally small in size, and lowly in development. It was, as it has been often called, "The Age of Reptiles," characterized by their abundance, magnitude, and variety. They filled the place of the whales and dolphins in the seas, of the herbivorous and carnivorous mammals on the land, of the vultures and cormorants in the air. They are unimportant, almost unknown, until the date of its earliest deposits; after this they rapidly rise to importance; they sink into insignificance, with curious abruptness, at its close. The invertebrates, however, gradually present a closer resemblance to the forms which yet exist. Not a few genera which still survive make their appearance in the Secondary era; but, as a rule, those which are now common were not very abundant then, while those which were important then are now either extinct or comparatively rare. This is generally true of the corals, the echinoids, and the mollusks, and the most striking fact connected with the last is the extraordinary development of the Belemnites and of the Ammonites, and their allies. These seem to run parallel with the peculiar reptiles, and they disappear as completely at the close of the era.

* H. N. Hutchinson's "Extinct Monsters," p. 107.

The fauna of the Tertiary era differs from that of the Secondary to a remarkable and, in some important respects, still unaccountable extent. Hardly a single species of the one era survives in the other, except in the case of some of the lowest organisms, where it is often difficult to fix the limits of a species, or, in other words, each type seems somewhat protean. In Britain the break between the two series is very great; in Northwestern Europe, as already said (p. 412), some rather scattered and fragmentary deposits help slightly in bridging the interval. In the Yellow Limestone, which at Meudon, near Paris, at Maestricht, and in the island of Faxoe, rests unconformably upon the White Chalk, genera belonging to the Cretaceous system are found associated with others characteristic of the Eocene; but the stratigraphical break disappears farther away to the southeast, in the area nearer to the Mediterranean Sea, where, however, fossils are generally rather scanty; while in the central and western regions of North America the transition from the Secondary to the Tertiary is stratigraphically complete. The Laramie beds (p. 329), which attain a thickness of some four thousand feet, if the flora alone were considered, would be regarded as Tertiary, but their fauna is more closely related to the Secondary. They contain some of the huge reptiles just mentioned, and certain of the characteristic Cretaceous genera of cephalopods, associated with other mollusks which are more distinctly Eocene. But the greatest puzzle is the comparatively rapid disappearance of the huge reptiles and their replacement by hardly less huge mammals. This, no doubt, may be partly explained by the fact that our idea of the later Secondary fauna is mainly gathered from strata which are distinctly marine, while the Laramie and earlier Eocene beds, when not actually fresh-water, are the deposits of shallow seas. This, however, by no means solves the difficulty. Some of the large reptiles of the Cretaceous period were either terrestrial or amphibious, living under conditions similar to the crocodiles, alligators, tortoises, and turtles of the present day. If, then, representatives of the latter reptiles are found (and by no means rarely) on both sides of the gap, why were not the dinosaurs able to cross it, and what part of the world witnessed the development of the large mammals which so quickly replaced them? These appear upon the scene like adults, like the first colonists of a new region, and we cannot find their nursery or their schoolhouse. Time may solve the riddle, future discovery may bring to light the "decline and fall" of the big reptiles and the contemporaneous rise of the big

mammals. In most of the regions hitherto examined this transitional period from the older to the newer era was evidently one of very considerable geographical, and probably also of climatal, change. Such a period would be likely to produce a corresponding effect upon the fauna, to be rapidly destructive to races accustomed to the old conditions—races which were the Bourbons of the animal kingdom, and could neither learn nor forget—and to develop with comparative rapidity those which were still plastic and capable of responding to stimulus. There may be to a species or a genus a time of senility and a time of adolescence, just as there is to an individual. It is obvious that in the Tertiary era the mammalia, as Professor Gaudry has remarked, were in the full swing of their evolution (*en pleine evolution*). Still the comparative suddenness of their appearance and of the disappearance of the great reptiles are facts—especially the former—which in the present state of our knowledge make a point for the advocate of special creation and are a difficulty to the evolutionist.

As the invertebrate fauna during the Tertiary era gradually approaches to its present condition, we need not enter into the details of the changes. Only a small number of the genera which existed at the outset have since become extinct, and the additions in this respect have not been large. The changes are chiefly in regard to species. According to Sir C. Lyell the percentage * of living species in the mollusca of the earlier Eocene deposits amounted to about 3½ per cent.; it rose in the Miocene to about 17 per cent., attained to from 35 to 50 per cent. in the older Pliocene, and became as high as from 90 to 95 per cent. in the newer Pliocene. These figures will give a rough idea of the gradual change. The most interesting significance of the invertebrate fauna—and this is corroborated, as already said, by the flora—is the evidence which it bears of very marked climatal changes, especially in the northern hemisphere. A glance at a collection of fossil shells from the London Clay, the Bracklesham, or the Barton beds of England, indicates, to anyone familiar with the present distribution of mollusks, the presence—nay, the marked predominance—of genera characteristic of tropical or sub-

* It was published in 1833. (See "Elements of Geology," ch. xiii. ed. 1865.) Subsequent researches have shown that the percentages cannot be regarded as very exact, and they are liable to local modification; at the same time they serve better than anything else to give a general idea of the progressive change toward the present condition of things. They would probably be roughly true for the invertebrates generally, but in the higher vertebrates the change is more striking, for a large number of genera have vanished, and existing species make a comparatively late appearance.

tropical regions. The earliest Tertiary deposit indicates a climate warmer than is now enjoyed by the corresponding locality—the temperature probably reached its highest when the Bracklesham beds were deposited, and then very slowly declined. Still, even in Miocene times, the climate all over Europe, and probably in all parts of the northern hemisphere, was more genial than at present. If we are permitted to fix one eye on the present age, and apply a geological telescope to the other, oleanders then might have been as gay in the parks of London as they now are in the shrubberies of the Riviera; and oranges, with their golden fruit, as in the streets of Spezzia, might have replaced the horse-chestnut or the plane in London suburbs. A gradual change in the same direction was in process all through Pliocene times, until at last an extreme of cold was reached as abnormal as the warmth had been, so that the musk-sheep found a congenial climate in the valley of the Thames. From these arctic conditions there seems to have been a gradual change to those under which we live. It is, then, obvious that, though the English climate is not beyond criticism, it has been worse.

Turning to the higher vertebrates, we find that both birds and mammals exhibit similar changes, but the remains of the former at present discovered are so much more scanty that it may suffice to say that one or two of the older Eocene forms, like those mentioned above, were dentigerous.* Existing genera, as a rule, cannot be recognized till Miocene times, and even then the correspondence is not very precise. In regard to the mammals much fuller information has been obtained, but the British deposits, owing to local circumstances, have not supplied important contributions to knowledge till the later part of the Tertiary. For the older mammalia, so far as the world has been hitherto examined, it is necessary to have recourse to the American continent, and especially to the western region of the United States. There, on the high plateaus west of the Rocky Mountains, in Southern Wyoming and in the adjacent parts of Utah and Colorado, is a thick group of deposits of lacustrine origin,† from which a great number of mammalian remains have been disinterred, which have been studied in

* The projections on the bill, however, are not teeth in so strict a sense as in the Secondary birds.

† According to Professor Marsh the vertical thickness of these deposits exceeds a mile. The district, now from 6000 to 8000 feet above sea level, is drained by the Green River, the principal tributary of the Colorado.

detail by Professors Marsh, Cope, and others. The creatures thus reconstituted are hardly less strange than the Secondary reptiles, which have been discovered in the same part of the continent. Truly America is the parent of prodigies, for its physical features and its palæontological products are alike on a grandiose scale. The shores of this lake were haunted by a strange group of monstrous beasts, which cannot be fitted exactly into any existing order. They are placed in that of the *Dinocerata*, or "fearsome-horned" mammals, because of certain protuberances on the skull, which suggest the presence of horns or organs of that nature. Taking as an example one of these, named *Dinoceras ingens*, we find that in the body it was something like an elephant, its head roughly resembled that of a two-horned rhinoceros, but it had besides two protuberances of smaller size, just above the nose, and two others, quite as long as the "nose horns," but rather blunter in form, above the ears. All these are actual bony protuberances on the skull,* and their external appearance is a matter of conjecture. Also the two canine teeth of the upper jaw were greatly elongated, especially in the male. The creature was about twelve feet long, not reckoning the tail. These Dinocerata, according to Professor Marsh, have been found as yet only about the Wyoming lake basin, none being known from any other part of America or from the Old World. Numerous other mammals are found, not only in the New World but also in the Old, in strata of Eocene and Oligocene age. Deposits now classed with the latter have given up several forms, both in the Isle of Wight and still more in the Paris basin. These, however, do not reach the gigantic size of the Dinocerata, but vary, like the ordinary European mammals of the present day, from the size of a large stag downward. It is difficult to class them with any of the existing orders for the reason already mentioned. Some present resemblances to tapirs, some to deer, some to pigs, some dimly foreshadow the horse, others might even claim a connection with the rhinoceros.

In the Miocene period the relationship to existing mammals becomes more strongly marked. North America still takes the lead in monsters, which come from the remains of an old lake basin, this time east instead of west of the Rocky Mountains, and near the present head-waters of the Missouri. This district was the principal resort of *Brontops* (thunder-face), a creature something like a rhi-

* This is not the case with the "horn" of the rhinoceros.

noceros, but with a pair of bony prominences above the nostrils. The head and neck were both longer in proportion than in that animal, the former being broad and shallow. *Brontops* was about twelve feet long, without the tail, and eight feet high. But though many strange forms continue to recall the older Tertiary mammals, we begin in the Miocene to meet with the ancestors, as they may be called, of families which still exist, both in the New World and in the Old. Marsupials were then much more widely distributed than now. Edentates (such as the sloths, armadillos, and ant-eaters) occur on both sides the Atlantic, and their representatives in the southern parts of Europe reached a large size. Cetaceans, allied to whales, seals, and sirens, make their appearance; beasts are found more closely allied to horses and deer, to the elephant, the rhinoceros, and the hippopotamus. In fact, the ungulate or hoofed quadrupeds are very numerous in the Miocene. The carnivora have hardly attained to their present importance; but the remains of simians, the family most closely related to man, have been discovered. One (*Dryopithecus*), from Miocene deposits in France and Hesse-Darmstadt, was an ape about as big as a chimpanzee, with teeth resembling those of the gorilla. In England the Miocene record is a total blank, but the Pliocene deposits, though of no great thickness, have yielded a fair supply of mammals. These have been largely augmented from the region bordering the Mediterranean, and yet more remarkably by the deposits of the Siwalik Hills in India. For this period the New World supplies less information than the Old. Among the most remarkable forms of Pliocene age were the giant tortoise of Northern India, the shell of which was not less than a couple of yards long, about double the length of the biggest now in existence, and the *Sivatherium* (beast of Siva), a ruminant bigger than any now living, for it was larger than a rhinoceros; this bore two pairs of horns, and seems in some respects intermediate between the giraffes and the antelopes. But in the Pliocene deposits, particularly in the upper portion, genera either still living or differing from these but little become common. The rhinoceros, the elephant, the hippopotamus, the horse, the bear, the hyena, the lion, are all in existence. In Europe alone there were at least as many species of rhinoceros, and more than as many of elephants, as there are now in the world. The great mastodons—creatures allied to the elephant—and the saber-toothed tiger (*Machærodus*) must not be forgotten. This also is worthy of notice. Excluding a few forms most common in the extreme north

of the two hemispheres, we find that a marked separation now exists between the mammals of the Old and the New World. In Pliocene times it was not so; a horse, a mastodon, an elephant, a rhinoceros, a tiger, a camel, not to mention others, formed strong connecting links between the two hemispheres. Professor Dana remarks on the animals which lived in the Upper Missouri region that "the collection has a strikingly Oriental character, except in the preponderance of herbivores."*

The post-Tertiary or Pleistocene does not require a long notice. In the earlier part of this period, if it may be so designated, a remarkably low temperature prevailed generally—at any rate, in the northern hemisphere. This displaced, and no doubt to some extent modified, the fauna and flora, but it does not seem to have effected any great destruction of species, and the chief change since that time has been the gradual disappearance of sundry of the larger mammalia, due probably in no small part, directly or indirectly, to the action of man. It may suffice, so far as the Old World is concerned, to indicate in a very few words the condition of our own land at a time when the Glacial epoch was passing away, and the climate gradually became less severe.

Britain at this time, as already mentioned, formed part of the continent of Europe, the North Sea, the English Channel, St. George's Channel being then dry land. Northwestern Europe, thus enlarged, exhibits a goodly list of large animals. Among them are two species of elephant; the one, *Elephas antiquus*, which more closely resembles the African elephant, may have been only a summer visitant to this country, in company with the hippopotamus; but the other, the mammoth, was a permanent resident, for it was protected by its woolly covering against all inclemencies of climate. There were also two species of rhinoceros, one of them being similarly clothed. Lions must have been as abundant in the lowlands round the Mendips as they were in the wilder parts of Southern Africa at the beginning of this century; the caves in many parts of England were the dens of hyenas; bears also were plentiful. Food for the predatory animals was not lacking; the broad lowlands, now sea beds, afforded ample pasture to droves of horses and herds of reindeer and red deer; and besides these were the urus, an extinct species of ox, and the Irish elk, also extinct; the bison, lingering now in Lithuanian forests, but then as common in Europe as till

* "Manual of Geology," p. 508, second edition.

lately its American relative was on that continent, while the wild boar and other smaller quadrupeds need not be mentioned. The condition of Western Europe in those days must have resembled, so far as the quadrupeds are concerned, that of North America or of Southern Africa before the gun or rifle of the white man had replaced the spears and arrows of the savage. That many of these creatures were hunted by man is a certainty. In not a few caves, notably in those of the Dordogne, the *débris* strewn upon the floor, and sometimes the rude carvings on bone and horn, show that the reindeer, the Irish elk, the horse, the bison, the ibex, the musk-sheep, etc., were hunted and were consumed by their inmates. Even the mammoth itself may have been a victim to their rudely chipped spear heads of flint, for its bones have been found, and a

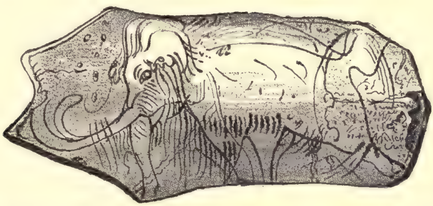


FIG. 163.—ENGRAVING OF MAMMOTH, FROM THE DORDOGNE CAVES (REDUCED).

fragment of a tusk bears a likeness of the beast, roughly engraved, but indubitable.

More marked changes in mammalian life are indicated in the southern hemisphere. In South America the fluviatile deposits of Pleistocene age, which form the widespread plains of Patagonia and of Brazil, have yielded the remains of gigantic allies of the sloths and of the armadillos. A species of *Megatherium* (great-beast), one of the best known of the former, was "fully equal in bulk to the largest species of rhinoceros," while *Glyptodon* (sculptured-tooth), which was more completely sheathed than the latter animals, was seven feet long in the body.

At the same geological epoch Australia possessed mammals of a larger size than at present are found within its limits. The latter, it is well known, represent only the lowest orders, the monotremes and marsupials; and a study of fossils indicates that in earlier times the higher orders were also wanting in this part of the globe. The predecessors, however, of the existing wombats and kangaroos some-

times attained to a great size. One of the former was probably as large as a tapir and of stouter build; another, *Diprotodon* (two-front-tooth), the representative of an extinct family, was much bigger, for it was equal in size to a large rhinoceros; a third, intermediate in zoölogical characters between these two, but about the size of the former, is supposed to have been a burrowing animal. There was also a predaceous marsupial, *Thylacoleo* (pouch-lion), as big as a lion. The kangaroos themselves have fossil representatives, some of large size. In New Zealand, as is well known, are no indigenous mammals, and none have been found fossil. But it was formerly inhabited by a huge and remarkable group of birds—the moa or *Dinornis* (terrible-bird)—still represented in that country by the little *Apteryx* or kiwi. This also seems to have had a giant predecessor, while the moas were often much bigger than the largest ostrich, one species standing about ten feet high. They were quite wingless, but their legs, as a compensation, were remarkably strong. Some species of a very large wingless bird (*Æpyornis*) have been also found in Madagascar, the largest of which rivaled in size the biggest New Zealand moa. The eggs of both these creatures have been discovered, and were proportionately large, that of *Æpyornis* being about fourteen inches in diameter. The moas undoubtedly survived in New Zealand till a comparatively late date, and were killed off by the natives; but in all probability some time before the arrival of the first English settlers.

Some remarks will be made in a later chapter on the significance of the present distribution of life upon the globe, and the relations of past and present forms. Here it may suffice to observe that a survey of palæontology leads us to the following general conclusions:

(1) That a group of living creatures, assuming its cycle to be complete, follows a course analogous to that of an individual. It appears, culminates, declines, and disappears.

(2) That, on the whole, there has been a progressive advance in organization; the work of life in the world, so to say, as time advances, is done by more highly developed creatures, though the "children of Gibeon" yet remain.

(3) That the earlier types are commonly of a more generalized character than their later representatives, according better with the more embryonic stages in the development of these, and frequently combining characters which are now divided among distinct groups.

(4) That, in the various quarters of the globe, ancestral forms of

the creatures which now occupy the same region may be found; but evidently the ancient geographical divisions often differed much from the present, and indications may be detected of the existence of communications which have been long severed.

(5) That in past times signs of climatal differences are exhibited which have affected the distribution of plants and animals, and can be traced back for at least a considerable distance in geological history, and that variations of climate have been a most important factor in the migration and distribution of species.

(6) That though a species seemingly makes its appearance and vanishes abruptly, this is not a safe basis for inference, owing to the known imperfection of the geological record, and that certainly there is not, even from the earliest epoch, the slightest evidence of any general catastrophic destruction of life and repeopling of the globe.

Part V.

ON SOME THEORETICAL QUESTIONS.

CHAPTER I.

THE AGE OF THE EARTH.

ONE other question claims attention before this story is brought to a conclusion—namely, What is the earth's age? In some of the preceding chapters the operations of processes destructive and constructive have been indicated. In those which followed the forms of living creatures, long since vanished, were sketched, and the connection between the present and the past disposition of land and water has been established, so far as the evidence admits. But these changes, this evolution alike of the earth's tenants and of its physical features, require time, and cannot be compressed into a few decades of centuries. Is it, then, possible to express this period, however approximately, by years, and to compare, however roughly, the duration of the earth with the life of man, although, perhaps, a millennial epoch of the one may be analogous to the day of the other?

A solution of the problem might be attempted by approaching it from the standpoint of the geologist. By means of numerous and careful observations an estimate might be formed, on the one hand, of the rate at which rivers lower their beds and seas encroach upon the land; on the other, of the time occupied in the accumulation of a certain amount of deposit, whether it be conglomerate or sand, fine mud or calcareous ooze. The thickness also of the different kinds of stratified rock might be ascertained, and then, after a careful estimate of averages, the time required to build up the complete series might be determined by a sum in simple proportion. This, however, at best, would be only a minimum estimate, for it would take no account either of strata which had been removed by denudation, or of certain metamorphic rocks, the origin of which is often doubtful. Great difficulty also at present exists in deciding what is a fair estimate for the thickness of the stratified rocks, and, lastly, the validity of any result obtained by applying the "rule of three" to geology is always open to question. Denudation and deposition proceed at such different rates under different circumstances; the

presence, or comparative absence, of vegetation; the character of the climate, whether equable or extreme, and many like disturbing causes, produce so much variation that it becomes extremely difficult to strike an average. We may steadfastly decline to accept the hypotheses of "convulsionists," and yet be consistent in believing that epochs of comparative unrest and of comparative calm may have alternated in one and the same part of the globe, and that a chronology, founded on the present condition of any region, may be easily either much in excess or much in defect of the truth.

Geologists, influenced strongly by the dictum of Hutton that the earth itself showed no trace of a beginning or sign of an end, had fallen, not many years since, into the habit of regarding past time as practically boundless. Like a young man who has come into possession of the wealth accumulated during a long minority, they appeared to deem the balance at their disposal inexhaustible, and drew checks lavishly on the bank of time. But just as a friend with wider experience might act the mentor to the spendthrift, so the physicist has uttered more than one warning to the geologist. Of these one is founded on the retardation of the earth's motion caused by the tides. It may be stated in the words of Professor G. Darwin:* "Since water is not frictionless, tidal oscillations must be subject to friction; . . . an inevitable result of this friction is that the diurnal rotation of the earth must be slowly retarded, and that we, who accept the earth as our timekeeper, must accuse the moon of a secular acceleration of her motion round the earth, which cannot be otherwise explained. It is generally admitted by astronomers that there actually is such an unexplained secular acceleration of the moon's mean motion." If this secular acceleration be estimated at a certain amount, "the earth must in a century fall behind a perfect chronometer, set and rated at the beginning of the century, by twenty-two seconds"; if this be so, "then a thousand million years ago the earth was rotating twice as fast as at present." But if it solidified either at that or an earlier epoch, this increase in the speed of rotation would impress upon the earth a form more distinctly spheroidal than its present one;† from this it may be inferred that solidification occurred at a much less remote period, when the speed of rotation corresponded more nearly with

* Address to Section "A" of the British Association at the Birmingham meeting, 1886.

† That is to say, the so-called circles of longitude would be more distinctly elliptical than at present.

the rate of to-day. Moreover, if the earth's form originally were more elliptical than at present, land should predominate over sea in its equatorial regions; but this, as has been already shown, is far from being the case. But to this remonstrance the geologist replies that the effects of denudation may have very materially altered the relative position of sea and land in the lapse of ages, and besides this, the present form of the earth may not correspond with the original one; for the material of which it consists may not be absolutely rigid, but may permit of its form being slowly adjusted from time to time to correspond with the rate of rotation.* In the latter contention the geologist would find that some physicists would come to his support.

Another warning is founded on the secular cooling of the earth. Lord Kelvin, in his well-known essay† on this subject, came to the conclusion that during the last 96,000,000 years "the rate of increase of temperature underground has gradually diminished from about one-tenth to about one-fiftieth of a degree Fahrenheit per foot." The rate of cooling thus indicated implies that in all probability not more than 100,000,000 of years, at a rough estimate, can have elapsed between the first formation of a solid crust on the globe and the present condition of things. But here also Professor Darwin has pointed out the possibility of a flaw in the argument, the result of which would be a lengthening of the time. But, in any case, whether this extension be allowed or not, whether the numerical value of the result may or may not be affected by the imperfections in certain data on which it depends, the main contention of the physicist holds good—viz., that there must be a limit, and this not an extraordinarily distant one, to geological time. Matters remained in this position till Lord Kelvin again startled the geologists by proposing a further curtailment of geological time by considering the problem from another point of view. Demur if you will, he seemed to say, to the tidal retardation of the earth and to the consequence of its secular cooling, but can you be certain about the duration of the sun? However long the earth has been in existence, for at least this time the sun must have been radiating heat into space. The amount can be estimated with some accuracy. Suppose it should be discovered that in the time which you geolo-

* If a flexible hoop were set rotating about a rod, upon which its upper part could move freely up and down, its form would become less or more circular as the velocity of rotation increased or decreased.

† Republished in Thomson and Tait's "Natural Philosophy," Appendix D.

gists demand, the light would have faded into darkness and the central fire would have gone out? Lord Kelvin has discussed the problem and arrived at this conclusion: "It seems, therefore, on the whole most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years. As for the future, we may say with equal certainty that inhabitants of the earth cannot continue to enjoy the light and heat essential to their life for many million years longer, unless sources, now unknown to us, are prepared in the great storehouse of creation."* But this conclusion also is not universally accepted, for some physicists maintain that such a source is even now in operation, and that the sun's heat is kept up—its fires, so to say, are fed—by the incessant shower of meteorites which is rained down upon it from celestial space. But though this process of "coaling the sun" may be really going on, though atom after atom in the incessant collisions may be changed from a solid to a vapor, and add its tiny quota of energy to the great central storehouse, there is no proof that space is studded so thickly with star dust as to compensate for the lavish expenditure of light and heat. Hence, though this income may postpone the final bankruptcy that fate seems to be inevitable.

Attempts, indeed, have been made, still in connection with the duration of the heat of the sun, to restrict the geologist within limits still more narrow than those just named—to allow only a very few millions of years for enacting all the drama of life. Here, however, he may justly make a stand. If he has been obliged to found his estimate of time upon uncertain data, the physicist also, as has been said, is in no better plight. In each of these three pieces of mathematical reasoning, as soon as any attempt is made to express the results in an arithmetical form, assumptions are introduced which cannot be regarded as beyond question, and the geologist is justified in retorting with a *tu quoque* on the physicist.

We come, then, to the conclusion, on a review of the whole subject, that the knowledge at present available is insufficient for an accurate solution of the problem, but that, on the one hand, the physicist can show that the earth and its order had a beginning, and that this must fall within a limit of time which would have been formerly deemed restricted—say, as a rough and outside approximation, something like 100,000,000 years—while, on the other hand,

* Thomson and Tait, "Natural Philosophy," Appendix E.

the geologist can show that, so long as we suppose the earth to have been governed by laws in general correspondence with those by which it is still regulated, the history of the stratified rocks and of the development of life cannot possibly be condensed into some twenty or thirty million years. In other words, we may affirm that the æon of the earth is long, but it is very far from being boundless.

CHAPTER II.

THE PERMANENCE OF OCEAN BASINS AND LAND AREAS.

WE have already shown that the changes in the physical geography of the globe have been many and great, so that the same spot on its surface may have alternated more than once between land and sea. This is universally admitted among geologists. But here agreement ceases. Some hold that our continents occupy the sites of ocean basins, and our oceans flow deep over submerged continents; while others maintain that, though there have been many oscillations of level, each large mass of land indicates a region which, from a very early time at least, has been more or less continental in character, and the deeper parts of the ocean, probably, have never risen above the surface. This question—the permanence of ocean basins, as it is called—is one which is no less interesting than difficult. The evidence upon which the answer must depend is mainly indirect; for, obviously, the deep sea guards its own secrets. We may, however, observe that the great size of the hollows of the ocean compared with the protuberances of the land masses, to which attention has already been called,* makes it probable that the deeper parts of the basins will be very persistent features of the earth's crust. But some inferences may be drawn from the rocks themselves, and some from the present distribution of life on the globe. If rocks are composed of ordinary detrital materials, such as thick masses of sandstone and silty clay, it may be justifiably assumed that they were deposited at no great distance from a considerable land area, generally at most not much more than a hundred miles, and very often less. Thus the building stones of the British Isles—and the same statement holds good of many parts of Europe—prove the proximity of ancient land masses. Deposits, however, occur at intervals—such as the Chalk or the Carboniferous limestone, which are conspicuously free from detrital material, and almost wholly composed of the *débris* of organisms.† But this does not necessarily prove that the water was deep—only

* Pp. 12, 59.

† See pp. 384, 449.

that it was clean.* The organisms of the Carboniferous limestone are so slightly related to living forms that they are of little avail for inductive reasoning as to their probable environment; but those of the chalk, in the opinion of zoölogists, do not indicate very deep water. At present, abyssal deposits† have not been generally recognized among continental rocks. No great stress, however, can be laid upon this negative evidence, because we have so little knowledge of what the very deep-sea deposits of ancient days would be like. A foraminiferal ooze would awaken suspicions, but it would not be conclusive, because many foraminifera live close to the surface; a radiolarian ooze would do this still more, because they can also live at a great depth, and their "tests" endure, whereas calcareous organisms are destroyed; a very fine, almost impalpable mud, which resembled a chemical precipitate rather than a detrital deposit, would be most of all suggestive; but to diagnose such a rock under the microscope would be, obviously, no easy task. Hence we cannot venture to say much more than that the constituent rocks of continents, while they undoubtedly give proofs of considerable oscillations, testify frequently to the proximity of ancient land, and rarely, if ever, demonstrate abyssal conditions.‡

But the comparative study of the faunas and floras of different regions seems to throw some light on the question.§ We have already given a brief sketch of the general distribution of life on the globe and the main laws on which it depends. We have seen that, frequently, one part of the fauna of a land region appears to be indigenous, but another part to be made up of colonists—the latter of course, as a rule, being a portion of the fauna indigenous in another region. Suppose that among these immigrants certain creatures are found to which seas would be an insuperable barrier, which can neither fly nor swim, such as most mammals and certain

* See pp. 365, 385.

† Such as are now found at depths approaching or above 2000 fathoms. See p. 185.

‡ I am well aware that during the last few years several such deposits have been claimed as abyssal muds; but when these are found associated with or in close contiguity to fairly sandy beds, I think we may venture to question the accuracy of the diagnosis. Though every abyssal deposit may be a very fine mud, the converse statement need not be true.

§ This has been thoroughly discussed by Dr. A. R. Wallace in his two most important works, "Island Life" and "The Geographical Distribution of Animals," and a critical summary of his views will be found in Dr. W. T. Blanford's Presidential Address to the Geological Society.—*Quarterly Journal*, xlvi. (1890), Proceedings, pp. 59–107.

reptiles. Their presence indicates that the two countries must have been formerly connected, directly or indirectly. If the number of the common forms is large and the correspondence close, the severance probably is comparatively recent; if the contrary, it may go back to very remote ages.

It has been found that the faunas* of certain regions, at present separated by wide and deep seas, contain closely allied forms. For example, the island of Madagascar is separated from Africa by a channel about 250 miles in width and not less than 1100 fathoms in depth. But the mammalia of Madagascar are related to those of Africa closely enough to show that both must have had a common origin, or the countries have been once united. The separation, however, probably goes far back into Tertiary times, for only two genera are common to both sides of the Mozambique Channel. One of these is a species of river hog (*Potamochœrus*). This, indeed, can swim, but in all probability would be unable to cross a strait twenty miles in width. It is, then, likely that at a comparatively late epoch in the Tertiary era Madagascar was not more widely separated from the mainland than England is from France at the present time. Similar evidence is afforded by the birds, reptiles, batrachians, and fresh-water fishes. All testify not only to a former connection, but also to an actual severance before the numerous genera, which at present are especially characteristic of the African fauna, migrated thither from more northern regions.† But the fauna of Madagascar, as well as those found in the Seychelles and the Mascarene Islands, which are allied to the former, suggest also that a connection once existed between this and an Oriental region. The resemblances are more marked among fossils than among recent forms, so the severance probably took place at a very ancient date. They are, however, sufficient to make it probable that so late as the Secondary Era there was a "land union between India and South Africa across the Indian Ocean." Mr. Blanford, after a careful and critical review of the evidence bearing on this question, comes to the following conclusion: "So far as I am able to judge, every circumstance as to the distribution of life is consistent with the view that the connection between India and South Africa included the Archæan masses of the Seychelles and Madagascar, that it continued throughout

* The same is true of the flora; but we restrict ourselves to the faunas because, on the whole, plants are more readily dispersed than animals.

† They were probably driven southward by the cold of the Glacial epoch.

Upper Cretaceous times, and was broken up into islands at an early Tertiary date. Great depression must have taken place, and the last remnants of the islands are now doubtless marked by the coral atolls of the Laccadives, Maldives, and Chagos, and by the Saya de Malha bank."*

Again, there is evidence to indicate that Australia was originally connected with New Zealand on the one hand, and even with South America on the other. Yet between it and the former the channel is always more than 1000 fathoms deep, though it is greatly narrowed in the direction of Queensland by a long spur, which extends from New Zealand toward the northwest, while Australia is separated from the American continent by the whole breadth of the Pacific. There is, however, a very considerable area bordering the Antarctic land region over which the sea is comparatively shallow, but this plateau is separated from both the Australasian and the South American continents by a fairly broad and deep channel; still a rise of about 1000 fathoms would increase the Antarctic area to continental magnitude, and almost link it with the other two, when they were correspondingly enlarged.

We have dwelt, of course, upon one side of the evidence, and there is more of a like kind. That which points in the opposite direction can be inferred from what has been already said as to the distribution of life; but a discussion of its details would occupy more space than can be spared. On the whole, however, Dr. Blanford's conclusion seems fully warranted by the facts—namely, that "while the general permanence of ocean basins and continental areas cannot be said to be established on anything like firm proof, the general evidence in favor of this view is very strong. But there is no evidence whatever in favor of the extreme view accepted by some physicists and geologists that every ocean bed, now more than 1000 fathoms deep, has always been ocean, and that no part of the continental area has ever been beneath the deep sea. Not only is there clear proof that some land areas lying within continental limits have at a comparatively recent date been submerged over 1000 fathoms, while sea bottoms now over 1000 fathoms deep must have been land in part of the Tertiary era, but there are a mass of facts, both geological and biological, in favor of land connection having formerly existed in certain cases across what are

* Presidental Address, *Quarterly Journal of the Geological Society*, xlvi. (1890), p. 98 (Proceedings).

now broad and deep oceans." In other words, we might venture to say: Continents may be broken up into groups of islands, and may be again united; they may be augmented by the conversion into mountain zones of considerable tracts, which once formed marginal areas of submarine deposit, and the peculiar tendency to "dimple"* which is exhibited by the earth's crust may lead to the formation locally of deep basins among the island groups. In like way the bed of an ocean may locally buckle up, or a tract of land may be involved in an extensive downbending of the earth's crust. Nevertheless it is more probable, on the whole, that continents indicate regions over which land has dominated from very early days, and that the profounder depths of the ocean basins mark the centers of large areas which have been even more persistently submerged.

* See, among others, the curious basins in the Banda and Celebes Seas, that between New Guinea and the Caroline Islands, and the deep hole found by the *Challenger* south of the Ladrone Islands.

CHAPTER III.

CLIMATAL CHANGE: ITS CAUSE AND HISTORY.

AT a geological epoch comparatively recent the climate of this country, probably also of a large part of the northern hemisphere, was much colder than it is at present; at one, much more remote, it was almost certainly considerably warmer.* Is it possible to account for these changes? The climate of any place depends primarily upon its latitude, secondarily upon its position in regard to the sea, and a number of other less direct causes, such as the influence of winds and ocean currents, the distribution of land and water (*i. e.*, whether its position is continental or insular), and the like. The climate, in short, of any locality is the result of many complicated conditions, and the courses of the isothermal lines at the present day by no means correspond with the circles of latitude. This is true of both the monthly and the annual isotherms. For instance, the summer isotherm of 59° F. passes through the north island of Japan to near Kolymsk, and takes a fairly regular course through Asia to Archangel, whence it goes by the top of the Gulf of Bothnia to Edinburgh and Belfast; from Ireland it crosses the Atlantic to America, running north of Quebec, and across the continent to north of Vancouver Island. Between its highest latitude on the continents of Asia and America and its lowest on the ocean there is found a difference of more than twenty degrees. If we follow the winter isotherm of 5° F. (which also passes through Archangel) we find that it runs to that city from St. Lawrence Island (south of Behring Strait) through Central Siberia and Orenberg; it then grazes the top of the Gulf of Bothnia, rising thence sharply northward to the south of Spitzbergen, whence it slopes down to pass to the south of Disco Bay, in Greenland, and then by Lake Superior across the American continent.† The difference of latitude between the extreme positions on its course amounts to over twenty-five degrees. Lastly, the path of the annual isotherm of 32°, to which we shall have to refer again, exhibits an irregularity

* See pp. 393–396 and 470, 471.

† Its course is roughly parallel to that of the line of 32° in the annexed chart.

no less marked. It "descends in Eastern Siberia rather south of the latitude of London; it rises very gradually as it proceeds westward as far as Tobolsk (lat. 58° 21′), whence it ascends more rapidly to Archangel, and then twists up in an S-like curve through the north end of the Gulf of Bothnia, overleaps the North Cape, and passes within the 70th parallel of latitude; thence it gradually falls, grazes the northwest coast of Iceland, cuts Greenland a little to the

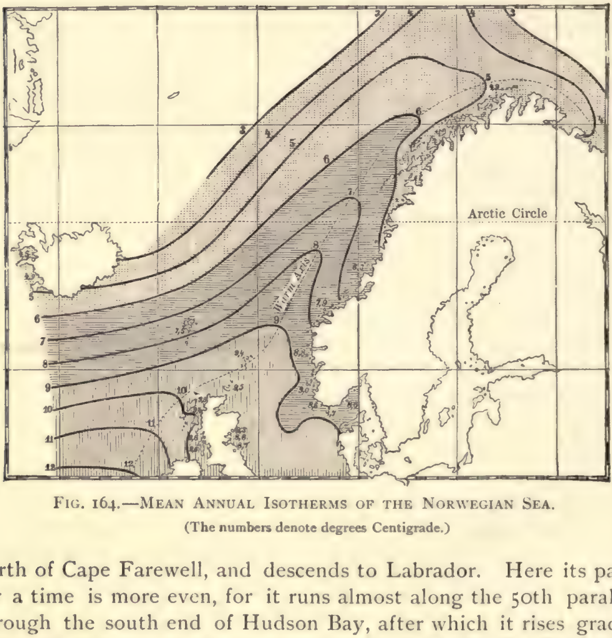


FIG. 164.—MEAN ANNUAL ISOTHERMS OF THE NORWEGIAN SEA.
(The numbers denote degrees Centigrade.)

north of Cape Farewell, and descends to Labrador. Here its path for a time is more even, for it runs almost along the 50th parallel through the south end of Hudson Bay, after which it rises gradually until it passes along the promontory of Alaska."* There are, accordingly, considerable tracts, both in Eastern Asia and in Northern America, in which the mean annual temperature is less than 32°. In the southern hemisphere also the temperature is lower than that of England in corresponding latitudes. "The mean temperature of Tierra del Fuego is 42° F. These islands correspond roughly in latitude with the eastern counties of England,

* This and the following extracts are from an article by the author, on "Geographical Changes and the Glacial Epoch," in the *Contemporary Review*, 1891, p. 716.

where the temperature is seven or eight degrees higher. That of South Georgia, which corresponds in position with the latitude of York, exhibits a similar difference. Here the climate is most inclement, the mercury, even during a midsummer day, not rising more than ten degrees above the freezing point." In the Straits of Magellan the temperature is quite eight degrees below that of corresponding positions in North Wales. In short, the climate of

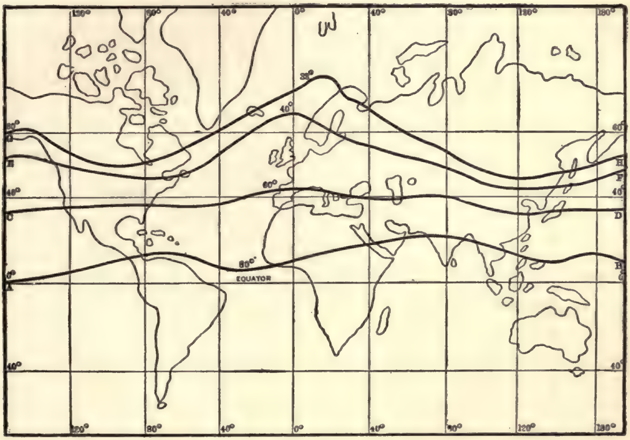


FIG. 165.—DIAGRAM OF THE COURSE OF THE WINTER ISOTHERMS IN THE NORTHERN HEMISPHERE.

Great Britain, much as it is abused, is abnormally warm, owing to influences which have been already mentioned.* It is not, however, sufficient to suppose them removed, for any explanation of the low temperature of the Glacial epoch must apply to Europe, at any rate from Scandinavia to the Alps, and to North America.

By what amount must the temperature have been lowered? The answer to this question depends to some extent upon the limits assigned to the land ice, on which point opinions differ, but if we take the more restricted limits—*i. e.*, those accepted by the most moderate school of glacialists, we shall have ascertained what is the least possible change. Glaciers will not form till the temperature is rather below 32° F. If Wales is to produce large ice-streams

* In Part I., ch. iii. and iv.

the temperature at the seacoast, which is now 50° F., must be lowered by about 18° F. Perhaps even this would barely suffice; so we may say that all geologists would agree that, in part of the great Ice Age, the temperature of the British Isles must have been lower than at present by not less than 20° F. The huge ice-sheets which once flowed from the Alps might be brought back by a drop of 18° F.; that of North America, which was yet more gigantic,†

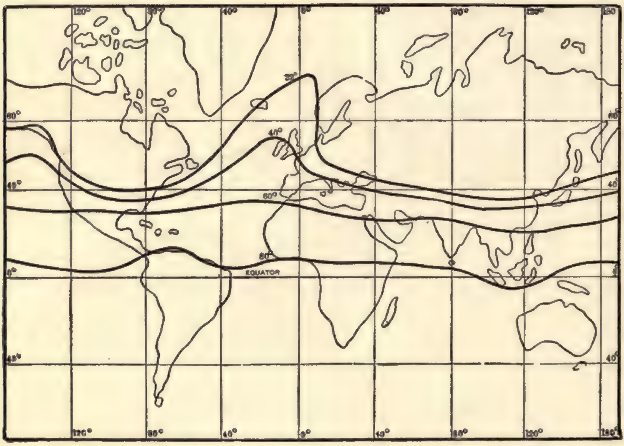


FIG. 166.—DIAGRAM OF THE COURSE OF THE ANNUAL ISOTHERMS IN THE NORTHERN HEMISPHERE.

might be restored, if other conditions were favorable, by a lowering amounting to about 16° F.

By what changes could this alteration of temperature be made? So far as Britain is concerned, a general rise of the land would have a double effect. It would increase not only the height of the mountains, but also their distance from the sea. Suppose North Wales to receive a further elevation of 2000 feet; this alone would make a difference of 7° F.,* to which, perhaps, in the case of the Carnarvonshire lowlands, 4° F. should be added for increased distance from the sea. This would account for fully half the amount required. But it is generally estimated that at the present time

* See p. 425.

† As a rough average we may take 1° F. for each 300 feet of ascent.

the climate of this part of Wales is raised by the effects of the Gulf Stream—in the opinion of some authorities, as much as 7.5° F. If, in addition, that current were diverted, the temperature might be lowered by about 18° F.—that is to say, the cold would probably be as great as it was in all but the severest part of the Glacial epoch. A like elevation would produce a similar effect in both the Alps and Canada, but here the Gulf Stream must not be taken into consideration, since on the former it has little influence, and in the latter none at all. So in all these cases such an amount of geographical change as might be called reasonable would fail, even under the most favorable circumstances, to give a temperature sufficiently low.*

The southern hemisphere emphasizes the fact that a somewhat abnormally mild climate is enjoyed by the western side of Europe, especially in winter time, but it does not provide an instance of a temperature at any corresponding latitude low enough to be compared with that of Britain in the Glacial epoch. We might, however, be asked: Is this material to the inquiry? for have we not already admitted that there are places in the northern hemisphere itself with a temperature 20° lower than that of the British Islands? This is true, but we must not forget that to place the latter under similar circumstances to the former would require physical changes on a scale far greater than would be justifiable at this late geological age. Some geologists hesitate to concede the possibility of a movement, either in an upward or in a downward direction, of as much as 1500 feet.† We certainly cannot venture to convert the Atlantic into a continent; and if this were done without some extensive compensation, it is doubtful whether, however severe the cold might be, the air would not be too dry for the production of an ice-sheet. In fact, each attempt to account for the Glacial epoch solely by terrestrial causes places us on the horns of some dilemma.

* Of course, if we are right in supposing that a good deal of the English bowlder clay was formed under water, elevation could not be assumed at a time when a seashore temperature of 32° F. (annual) with a severe winter climate, would be required. There is, however, evidence (page 395) that just before the Glacial epoch, perhaps also at the time of the largest ice-sheets, the land stood higher than at present. Possibly in this country the time of maximum cold did not correspond with that of maximum elevation.

† The peculiar powers of ice-sheets in collecting specimens from the sea-bottom and transporting them to inland localities, referred to on page 396, have been devised to escape from this supposed difficulty of a downward movement of the above amount during Glacial epoch.

But even if all these difficulties were successfully overcome, if land and water were so arranged as to bring about the low temperature required, we are then called upon to account for an elevation of temperature not less marked. It has been estimated that the climate of Switzerland in Miocene times was about 16° F. above what it is at present, and in the preceding period higher still by perhaps 4° F. The fauna and flora of the Eocene in England concur in indicating a temperature which was at the least 20° F. above

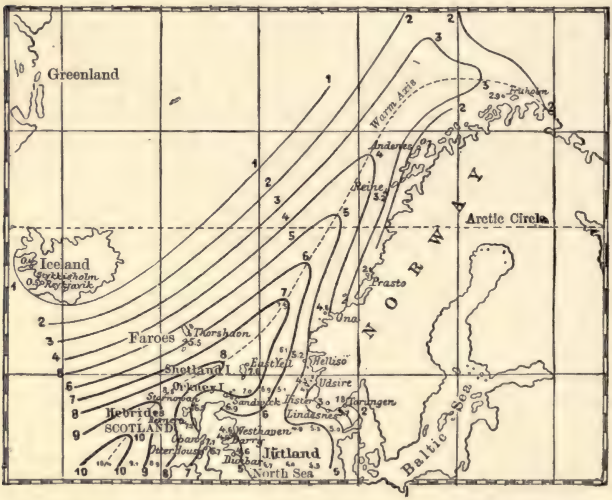


FIG. 167.—SURFACE ISOTHERMS OF THE SEA IN JANUARY AND FEBRUARY, INDICATIVE OF PROBABLE EFFECTS OF GULF STREAM.

(The numbers denote degrees Centigrade.)

that of London; yet we have already observed that the English climate is now abnormally warm.

Prior to the Tertiary era the fauna and flora* differ so much from that which now exists that it is extremely difficult to use them in making inferences as to the climatal conditions which may have existed in any part of the earth. The evidence, however, such as

* Strictly speaking, the flora approaches the present type a little earlier, *i. e.*, at the end of the Neocomian period.

it is, suggests, on the whole, a climate warmer rather than colder than it is at present. At any rate, there is little indication of anything like a Glacial epoch. Bowlders here and there, as in the chalk, or even in the coal, may suggest the possibility of floating ice; but in this, supposing rather different geographical conditions, there would be nothing surprising. The curious breccias and large bowlders* in the flysch of the Alps, and those described by Professor Judd† in the Upper Oolite of Sutherlandshire, suggest the action of ice. The Permian breccias of Central England‡ and the bowlders in the Talchir group of India § (to mention no other cases) suggest the possibility that a low temperature was generally prevalent somewhere about the epoch when the Primary passed into the Secondary era. Still the evidence of anything comparable with the conditions during the Glacial epoch is extremely doubtful, if, indeed, it be not wholly wanting.

Sir J. Evans has suggested an hypothesis which would afford a ready explanation of climatal change. Supposing the earth to consist of a solid outer shell resting on a fluid interior, the transference of sediment from place to place, and the upheaval of mountain chains, may make a change in the direction of the axis of rotation of this shell, while that of the mass, as a whole, is practically unaffected. The shell accordingly will slip over the inner mass into a new position, and the geographical station of the poles will be altered. It may be doubted, however, whether the fluidity of the interior would be such as to permit of any sliding about of the crust except under conditions so extreme as to be very improbable, and mathematicians assert, after making calculations, that no change, which may be regarded as practically possible, would affect the position of the poles by more than two or three degrees. The hypothesis also would not be any real help in explaining the climate of the Glacial epoch, for palæontological evidence shows

* In the Habkerenthal, near Interlaken, these are sometimes about thirty cubic yards in volume; near Sepey, Val des Ormonds, they are almost as large. It should be stated that opinions differ as to the mode of transport of these bowlders, and to attribute it to ice raises some serious difficulties, because, as has been just said, a warm climate seems to have prevailed in the earlier part of the Eocene, and the Alps were not upraised till a later epoch, so that the glaciers of a mountain chain seem to be excluded.

† *Quarterly Journal of the Geological Society*, 1873, p. 187.

‡ See a Paper by the author in the *Midland Naturalist*, 1892, February and March.

§ Bowlders (striated) also occur in the Olive group (*Geological Magazine*, 1886, pp. 492, 494); to this, however, some geologists assign a date which would bring it not far away from that of the flysch.

that in Tertiary, perhaps even in later Secondary times, climatal zones existed on the earth in positions generally similar to those which they at present occupy.

Is it, then, possible to find an explanation by looking beyond the surface of the earth? Some geologists have suggested that the solar system in its course through space may traverse regions especially cold or warm. This, however, is really taking a leap in the dark to avoid a difficulty, for there is little, if any, evidence in support of the hypothesis. Others have suggested that the sun may be a variable star. This is not in itself impossible, but in such case either the elevation of temperature would be rapid, though followed by a slow cooling, or, if the changes are both gradual, we cannot say how they are to be explained, and cannot find any proof of their occurrence. Moreover, if the fire needs to be occasionally stirred, to speak figuratively, it is difficult to understand how the poker is to be applied without a considerable risk to the complete stability of the solar system. Astronomy, however, discloses certain departures from a periodic uniformity which can hardly fail to produce some effect on the climate of the globe or of particular regions.

In the first place, the form of the orbit described by the earth about the sun is not fixed, but is constantly varying within certain limits, though with extreme slowness—it may be almost a circle, or it may be more elliptical than at present. Although this change of form does not much alter the total amount of heat received in a year, it very materially affects the distribution, because the more elliptical the orbit, the more unequal in length are the seasons. Thus the one hemisphere will have a long summer and a short winter, while the other has a short summer and a long winter. Moreover, in the latter case the summer will occur when the earth is at its perihelion distance, and the winter when it is in aphelion—so that the one season will be comparatively short and hot, the other long and cold—while in the other hemisphere the summers will be longer, but cooler, and the winters shorter and milder.

Even very competent judges are by no means agreed as to the effects which would be produced on climate by any possible changes in the form of the earth's orbit. All admit that the total amount of heat received during a year would be only slightly altered, but some maintain, with Sir R. S. Ball, that the changed distribution of it would produce a material effect. This is an outline of his development of an argument already advanced by the late Dr. Croll and others. There can be no question that the heat of the sun is

the sole factor of any importance in raising the surface of the earth to its present temperature. But for that this surface would be speedily chilled down to the temperature of space. Assuming the quantity of heat emitted by the sun to be constant, the amount which any place receives at a particular moment depends upon its position on the globe and that of the earth in its orbit. Changes in the form of the orbit, as already said, do not materially affect the

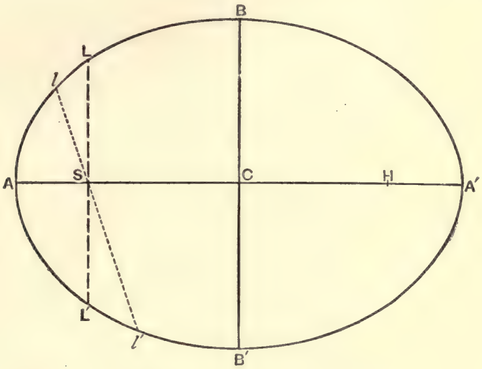


FIG. 168.—DIAGRAM OF AN ELLIPTICAL ORBIT.

A, A′, Major Axis; B, B′, Minor Axis; C, Center; S, H, Foci (S, marking position of sun). Suppose L L′ to indicate the position of the equinoxes, then it will be seen from the diagram that the seasons are very unequal in length. It must be remembered that the line L S L′ changes in position, as indicated by *l* S *l′*.

total quantity of heat received by the earth as a whole; also equal amounts are received in the perihelion and the aphelion portions of the orbit, as they may be called. This, however, is only true of the earth as a whole; the amount of heat received *by a particular hemisphere* in its summer and its winter season is always in the proportion of the numbers 63 and 37. The seasons, as already said, vary in length, but the greatest possible difference between them amounts to 33 days—*i. e.*, the one may be 166, the other 199 days. Suppose, then, that in England (and in the northern hemisphere generally) the winter season is 199 days long, and that during this period only 37 per cent. of the total supply of heat is received, this would produce a low temperature. For the summer there is a larger share distributed over a shorter time. Sir R. S. Ball illus-

trates the conditions which would prevail in the two hemispheres by the following calculations:

EXTREME CONDITIONS.

Northern hemisphere	Mean daily heat in summer (short)	1.38
	Mean daily heat in winter (long)	.68
Southern hemisphere	Mean daily heat in summer (long)	1.16
	Mean daily heat in winter (short)	.81

PRESENT CONDITIONS.

Northern hemisphere	Mean daily heat in summer (186 days)	1.24
	Mean daily heat in winter (179 days)	0.75

He makes use of a rough and homely comparison to illustrate the different conditions of a hemisphere under these altered circumstances. Suppose a man to have a fixed salary, which is paid in unequal installments. Let this, for example, be £100 a year, and let it be divided into portions of £63 and £37, which must be expended in the seasons for which they are paid. When there is the longest possible summer and the shortest possible winter, the man's daily portion amounts for the one to 6*s*. 4*d*., for the other to 4*s*. 5½*d*.—"under these circumstances, he enjoys a fairly beneficent arrangement." Now suppose the circumstances reversed: his summer daily allowance is 7*s*. 7*d*., but this comparative luxury has to be expiated in the winter, for then his allowance is only 3*s*. 8½*d*.* The illustration obviously, as its author would admit, does not represent the real circumstances of the case, but it helps in giving some idea of the marked contrast in the temperatures of the midsummer and midwinter months, which might result from an extreme eccentricity.

Indirect causes, however, would probably affect the climate under these exceptional conditions, and tend to increase the inclemency. By the end of the winter snow and ice would have accumulated in considerable quantities, and no very material rise in temperature could be produced until these were melted. During the thaw the air would be saturated with vapor, and clouds would be constantly forming. Thus, as soon as the sun began to produce an improvement, it would, like an injudicious reformer, arouse an opposition, which, to a certain extent, would counteract its benefits; so that, although the amount of heat transmitted ought to have made the summers warm, they actually, in all probability, would be rather

* Sir R. S. Ball, "The Cause of an Ice Age," p. 122.

cold. Even if it may be assumed that a change in the form of the earth's orbit produces a corresponding change in the climate of each hemisphere, we have not yet exhausted the possible causes of alteration. The actual position of the orbit varies, and the axis about which the earth rotates does not remain always parallel to itself. These movements are complicated in character. The principal one—that of precession—has been already explained,* but there are others as well. Let us recur to our original illustration, the knitting needle inserted into the model of the sun; this, in consequence of the movement just named, slowly and majestically sweeps out a cone in space, completing the figure in 25,868 years. But if we look more closely, we shall see that the cone is not perfectly uniform. The needle sways slightly backward and forward. Its motion is twofold; one, if no other effect had to be observed, would cause it to describe a very tiny ellipse,† and this, when combined with the precessional movement, would produce a slight "frilling" of the surface of the cone. The other motion is rather more important, but is less regular—less periodic, to use a more technical term. It is due to an oscillation of the earth's axis backward and forward for a space of about 1° 22′ on either side of 23° 28′, which was roughly its deviation from a vertical position in 1801.‡

The effect of this movement is to increase or diminish the tropical and polar regions, and correspondingly to restrict or enlarge the temperate zones. For example: if it be winter time in the northern hemisphere when the angle has its greatest value, the sun would not be seen at the December solstice anywhere north of the top of the Gulf of Bothnia,§ and, further south, would not be so high in the midday sky by nearly a degree and a half. This ought to produce a more marked difference between summer and winter, and to affect broad marginal zones, if nothing more, in the temperate regions.‖ The results, however, of this change would not be great, while we may venture to pronounce those of the former one quite inappreciable.

But the effect of the precessional movement ought to be impor-

* P. 315.

† The diameter is only 18.5 seconds.

‡ Strictly speaking, this is due to an oscillation of the plane of the orbit, as if, when a top was spinning on a table, that were very slightly tilted up and down.

§ More strictly speaking, lat. 65° 10′ N.

‖ The effect of this change is discussed by Dr. Croll in "Climate and Time," ch. xxv.

tant. This, however, must be regarded in combination with another movement already mentioned. Suppose the orbit represented by an oval groove cut in the surface of a table, and the earth by a top, and that as the latter is spinning in the grove the table itself is slowly turning round. The combination of this second movement with that of precession brings about a repetition of past conditions more quickly than would be effected by the latter alone; so that the earth's axis of rotation becomes parallel to its original position, not in 25,868 years, as mentioned above, but in 21,000 years. The effect of the precessional movement, if the northern hemisphere be taken as an example, is as follows: In the year 1248 A. D. midwinter occurred when the earth was in perihelion, or at its nearest distance from the sun, and so midsummer corresponded with the aphelion position. But about the year 9250 B. C. the seasons fell under circumstances exactly the opposite, and these will recur about 11,750 A. D. Whatever effects, then, precession may produce, they ought to alternate with some regularity; for the form of the earth's orbit changes very slowly, and the cycle of the precessional movement might be completed once or twice during the time when the eccentricity was near its maximum. Accordingly, the effects of the latter would be either intensified or mitigated in a particular hemisphere by the action of the former. For instance, about 9250 B. C. winter in the northern hemisphere fell in aphelion and summer in perihelion; hence if at that time the eccentricity of the orbit had been rather high, the cold, as already intimated, would have been severe, and the climate generally ungenial. But the conditions in the southern hemisphere would have been reversed, and the results very different. So far, then, as precession goes, the northern hemisphere has, for a time, seen its best days; but, as a set-off to this, the eccentricity is now diminishing.

Some geologists believe that the deposits belonging to the Glacial epoch indicate at least one alternation of mild with severe climates, and attribute this to the effect of precession. If such there be, the explanation would probably be adequate for the purpose, but the value of the evidence on which these so-called "Interglacial" ages depend is by no means universally admitted. Some geologists are of opinion that the oscillations in the magnitude of the glaciers were not greater than may be explained by changes of level or by climatal variations of a minor character, such as even now cause considerable fluctuations in the size of Alpine glaciers. These would make their effects still more perceptible on the greater ice-

streams, just as a water barometer is more conspicuously sensitive than a mercurial.

In the present state of our knowledge we are not in a position to express a very positive opinion as to the causes by which the climate of either hemisphere has been affected. The subject is an extremely difficult and intricate one, and the most competent judges are still at issue as to whether astronomical changes would or would not produce any very material effects. So far as I can form an opinion it seems to me certain on the one hand that geographical changes would be sufficient to produce very marked alterations in climate, but very doubtful on the other whether any such changes which could be reasonably assumed at so late a time would be sufficient to account for the existence of a very low temperature in so large a portion of the northern hemisphere during the colder part of the Glacial epoch. It seems also highly probable that changes in the eccentricity of the orbit and the results of the precessional movement would have, in general, the effects which have been ascribed to them above; the latter now intensifying, now tending to neutralize the former. So I regard the climate of any region, to use a mathematical phrase, as a function of three independent variables, which may at one time co-operate, at another time counteract one another. In the one case, they may produce either a Glacial epoch or an exceptionally warm period; in the other, the climate of any region may remain fairly normal—that is, may depend mainly upon latitude, or, at any rate, be little affected by astronomical causes. But I am doubtful whether even these causes, as at present understood, supply us with a complete explanation, for both the Glacial epoch and the long-continued warmth of the Eocene and Oligocene periods, so far as we know, are unique of their kind. I am accordingly disposed to think that either something remains to be learned about the effects of one or more of these variables, or some other factor affecting climate exists which is as yet unappreciated.

If, however, Dr. Croll be right in considering the changes of temperature, of which we have spoken, to be largely due to variations in the eccentricity of the earth's orbit, it should be possible to determine the period at which some of the latest of these occurred; perhaps even to construct an approximate chronology for the concluding chapters of the earth's history. If a formula could be obtained to express the value of the eccentricity at any time, directly or indirectly, in terms of the number of years which have separated that time from a certain date, the determination of this

number becomes merely a question of arithmetic. This difficult problem engaged the attention of an eminent mathematician (the late M. Leverrier), and he succeeded in constructing a formula which is believed to hold good, at any rate approximately, for four millions of years, past and future. From this formula the late Dr. Croll calculated the eccentricity of the earth's orbit, at intervals of 50,000 years, for three million years past and for one million of years to come. His well-known work gives the results of this laborious undertaking, and exhibits them in a graphic form.* At a glance it is evident that the variations are both great and irregular, for the curve resembles an exaggerated section of a series of mountain ranges. At the present time, it will be remembered, the eccentricity is comparatively small, and will continue to diminish for several thousands of years, so that even 50,000 years hence it will not be much larger than it is at present. Looking backward, we find that for a long time its present value generally has been exceeded, sometimes very greatly so. At a period of about 50,000 years ago the value declined for a time below the reading for 1800 A. D., but the next 300,000 years display a most unpromising record. Thrice during this period, at intervals fairly uniform, the eccentricity rises to a high figure.† The first occurred about 100,000 years since, when the eccentricity was nearly treble its present amount; it then declined, though still remaining high, the minimum value, which fell rather less than 50,000 years farther back, being roughly double the present one. A little after the end of the 200,000 years' period it attained its maximum; at 250,000 years it fell again slightly below the former minimum, but some time after 300,000 years reached another maximum—that is to say, the eccentricity did not fall nearly so low as its present value, during a period which began 50,000 years back, and lasted for 300,000 years, while it was extremely high at the following (very approximate) dates: 100,000, 200,000, and 300,000 B. C.—in other words, the Glacial epoch might be regarded as lasting about 300,000 years, and ending about 50,000 years ago.

These are figures which we can handle, and, to some slight extent, attempt to check by the results of inductive research in other directions. Dr. Croll points out that this interval is suffi-

* Croll, "Climate and Time," ch. xix.

† The figures are .0473, .0569, .0424, as against .0168, the present value. If we use the illustration of a mountain chain, they may be represented as hills of 4730, 5690, and 4240 feet, as against one of 1680 feet high.

ciently long to admit of each hemisphere being affected in turn by the results of precession, while the changes are sufficiently slow to allow the effects of a high eccentricity to be more than once mitigated or intensified. Within 100,000 years nearly five complete precessional cycles are included, for in 10,500 years a hemisphere passes from the condition of winter in aphelion to that of winter in perihelion, so that the effects of a changing eccentricity would be intensified or mitigated. Suppose, for example, that about 200,000 years ago, when the eccentricity had risen to its highest value, we consider the case of the northern hemisphere; it should suffer, according to Dr. Croll's view, from a glacial epoch of exceptional severity, the winter occurring in aphelion. At the end of 10,500 years, while the eccentricity is still high, but is decreasing, this season falls in perihelion, so that the result should be a considerable improvement in climate. At the end of another 10,500 years winter again falls in aphelion, and the climate should become more inclement; but, as the eccentricity has continued to diminish, the one change to some extent should neutralize the other. Similar conditions should recur, so far as precession is concerned, approximately at the following periods: 179,000, 158,000, 137,000, 116,000, 95,000 years, while the eccentricity fell to its smallest value rather less than 150,000 years ago, and rose to its next highest value at about 100,000 years. The latter date corresponds very nearly with the quarter point, as it may be called, in the precessional cycle; so that any climatal alteration would be probably due to the changed value of the eccentricity. But, as the latter reached its minimum rather less than 150,000 years ago, the effect of precession would lead, on the whole, to a further amelioration of climate in this hemisphere. This long period—over 250,000 years—during which the eccentricity continued well above its present amount, would give ample time for extension of glaciation in this hemisphere; and the precessional movement—at one time intensifying, at another neutralizing the effects of a high eccentricity—would explain the apparent oscillation of temperature exhibited in the alternations of bowlder clays and sands, and the intermingling of the faunas seemingly representative of rather different climates.

At first sight Dr. Croll seems to have made out a strong case in favor of placing the Glacial epoch during this interval of 250,000 years; but difficulties arise on a closer study of the question. During the remainder of the 3,000,000 years, for which the calculation has been made, the eccentricity generally has ruled considerably

above its present value. Only four times did it fall materially below this; eight times it was above the lowest of the three maxima attained during the Glacial epoch, and quite as often very nearly equal to the same, and thrice it much surpassed the highest of them. These were 850,000, 2,500,000, and 2,600,000 years ago.* A very low eccentricity (.0053) occurred 2,650,000 years since. If we suppose this to have corresponded with the warmer part of the Eocene period, the climate of Europe should have been seldom better, and commonly worse, than at present, while at least one very severe glacial epoch should have occurred in the Eocene itself. Notwithstanding the possible significance of the singular bowlders and breccias in the flysch, the fauna and flora of the Eocene seem irreconcilable with the hypothesis of the continuance of a cold climate for any considerable time; and the general impression conveyed by palæontology, throughout the greater part of the Tertiary period, is totally opposed to the existence of conditions which seem to follow from the record itself, when interpreted in accordance with Dr. Croll's own principles. Of course, if geological time be extended far beyond the limit of a hundred million years, the whole of the record from which the calculation was made might be regarded as covering only the later and colder portion of the Tertiary era, but then other difficulties will have to be confronted. The date assigned to the Glacial epoch by these calculations and inferences—viz., from about 350,000 to 50,000 years ago—may be checked, to some extent, by an endeavor to estimate the time which has elapsed since the retreat of the ice, from the amount of erosion which has subsequently taken place. On this point, as might be expected, great diversity of opinion exists. Certain American geologists—from observations at various places, such as the shores of Lake Michigan, some gorges on the Mississippi, the Falls of St. Anthony, sundry tributaries to Lake Erie, and the Falls of Niagara†—place the melting of the ice at not more than about eight thousand years back. This date, as already said, seems improbably recent; but there is evidence at any rate sufficient to make us cautious in claiming a very remote date for the Glacial epoch, so that we can hardly venture to look beyond the one which, as stated above, corresponds with the last triple group of high eccentricities.

* When the eccentricities are respectively .0747, .0721, and .0660.

† See Wright, "The Ice Age in North America," p. 549. The general aspect of the valleys in the Alps indicates but little change since the ice left them.

There is yet another difficulty, at which indeed we have already hinted—namely, that if this calculation allows any inference to be drawn as to the history of the earth in ages still more remote, its climate, on the whole, ought to have been less genial than at present, and glacial epochs to have occurred rather frequently. No doubt it is extremely difficult to arrive at any conclusions on these points, and especially on the former; but, as already said, such evdience as we possess tends in the opposite direction. Dr. Croll, it is true, has endeavored to show that indications of glacial epochs are not unfrequent among the stratified rocks; but most of the cases which he brings forward appear to me to rest on very slender evidence, and his efforts to account for the absence of any of a more convincing character to be far from successful.

So the question of the date of the Glacial epoch seems, in the present stage of our knowledge, to be hardly more capable of solution than that of its cause. It may be rather humiliating to make the confession; but in these problems, as in so many others, we must be content to give a hesitating answer, to state the facts and indicate the directions in which they tend, and to leave the complete solution—if, indeed, that be ever accomplished—to a future generation, which will have added to our knowledge and learned from our mistakes.

CHAPTER IV.

THE DISTRIBUTION AND THE DESCENT OF LIFE.

THE problem of the distribution of life on the surface of the globe is so difficult and intricate that if anything more than the merest outline were attempted, this book would be enlarged beyond all reasonable limits. Perhaps a general idea of the leading principles by which it appears to be regulated will be most easily obtained from a brief summary of a few important facts which are afforded by the study of the flora and fauna of one or two districts. We may take, as the first example, the British Isles. Their flora is closely related, on the whole, to that of France and Germany; the distinctions are hardly more than varietal, but the number of species is smaller. It is accordingly inferred that till a comparatively late age Britain was connected with Western Europe, and this is fully borne out by geological evidence. But one or two local peculiarities are exhibited by the flora which call for explanation. For instance, a small group of plants flourishes in the south-west of Ireland—such as the strawberry tree (*Arbutus unedo*), the Mediterranean heath (*Erica mediterranea*), the London pride (*Saxifraga umbrosa*), and two or three other species of that genus—which now are not found elsewhere north of the Pyrenees and Alps.* Again, in parts of Cornwall and Devon a second group of plants is found—including the tamarisk (*Tamarix gallica*), the autumn squill (*Scilla autumnalis*), the Cornish heath (*Erica vagans*), and the ciliated heath (*E. ciliaris*)—for which we must generally go to the southern or western parts of France. A third group of plants clusters around the mountain summits, which thus may be compared to botanical islands. These plants—such as the moss campion (*Silene acaulis*), the mountain saxifrage (*Saxifraga oppositifolia*), the dwarf azalea (*Azalea procumbens*), the snow gentian (*Gentiana nivalis*), etc.—are found in abundance on the Pyrenees, the Alps, and the greater part of Norway, some being confined to

* There are also two American species, one of which—the pipe-wort (*Eriocaulon septangulare*)—is found in the Hebrides, as well as the west of Ireland.

the last-named region. Plants also, strictly Scandinavian, are more numerous in the northern than in the southern parts of Britain; for example, *Primula scotica* is limited to the northern shores of Scotland; *Cornus suecica*, *Trientalis europæa*, and *Rubus chamæmorus* get down as far as the Yorkshire hills, but only the last to the mountains of Wales. On consideration of the circumstances associated with the distribution of this last group, the conclusion seems warranted that it contains representatives of the plants which occupied the British Isles and the adjacent parts of Europe at or about the time of the Glacial epoch; these, as the climate became less severe, would find the lowland regions unsuitably warm and would retreat into the uplands. On the lower hills they would be, as it were, drowned by the advancing waves of heat, but in the more mountainous districts some would find camps of refuge. Obviously the safest and the most general line of retreat would be toward the north, which accounts for the British plants having a closer connection with the Scandinavian flora than with the Alpine. From the north these plants probably came as invaders when the cold was increasing; to it they were driven back "like a beaten army" when the climate again became warmer. But how are the other two insulated groups of plants to be explained? Some have considered them indicative of a direct land connection, in very late geological times, between Southern Ireland, Cornwall, and the Spanish peninsula. So far as regards the plants common to the southwest of England and the Breton promontory or the Channel Islands, this is a possible explanation, but it can hardly apply to those in the first group, for the great depth of the Bay of Biscay and of the sea between Ireland and Portugal makes it improbable that these were directly linked together by a land mass at so recent a date. I am accordingly disposed to regard the latter group, if not both of them, as survivors of the flora which occupied Western Europe in Miocene and Pliocene times, and contrived to survive the Glacial cold, in certain more genial nooks on the border of the Atlantic, as persons of delicate constitution at the present day betake themselves to the sunny shore of the Riviera.

But the ordinary British flora is undoubtedly an immigrant from the mainland of Europe. It contains fewer species, and hardly any that are peculiar.* The same may be said of the fauna. About 2

* According to the late H. C. Watson, there is no plant peculiar to the British Isles which can be regarded as more than a variety or, at most, a sub-species.

species of mollusca, 72 species of coleoptera, 69 of lepidoptera, 15 of fishes, and 3 of birds are peculiar to the British Isles, but most of them are closely allied to continental forms. For instance, the red grouse (*Lagopus scoticus*), which is the most markedly distinct bird in these islands, is nearly related to the willow grouse of Scandinavia. As Mr. Wallace points out,* the evidence of the mammals, reptiles, and amphibia is remarkably convincing. In Germany are 90 species of mammals; in Britain, 40; in Ireland, 22. In Belgium the reptiles and amphibians number 22 species; in Britain, 13; in Ireland, 4. These statistics lead to three conclusions: one, that the fauna spread gradually from the east or southeast into these islands; the second, that Ireland was separated from Great Britain while the latter was still connected with Europe; the third, that the differences of environment have produced some slight effects on certain of the forms thus insulated.

We pass on to the Azores. This group of islands—nine in number—extends, from the southeast to the northwest, over a distance of nearly 400 miles, the nearest being not quite 900 miles away from the Portuguese coast, and separated by a part of the ocean 2500 fathoms deep. The following is a brief summary of Mr. Wallace's remarks: There are no indigenous land mammals, no amphibians, no snake, lizard, frog, or fresh-water fish; in a word, no terrestrial vertebrates;† but winged creatures, such as birds and insects, are abundant; and there is even a flying mammal—a small European bat. The birds are 53 in number, mostly species that are strong on the wing. Of the land birds, 18 in number, all except three are common in Europe or North Africa. Of these, two inhabit Madeira‡ and the Canary Islands; and one, the Azorean bullfinch, is peculiar to the Azores. The beetles number, at present, 212, of which 175 are European; but probably only 74 are really indigenous; 36 species are not European, of which 19 are natives of Madeira or the Canaries, and are altogether peculiar to the Azores. Of the land shells there are 69 species, of which 37 are common to Europe or to the other Atlantic isles, while 32 are peculiar, though almost all are distinctly allied to European types. The majority of these shells, especially the peculiar forms, are very small, and many of them date back to beyond the Glacial epoch.

* "Island Life," p. 319.

† There are a few mammals, some fish, and a lizard, but there are reasons to believe these have been introduced.—"Island Life," p. 240.

‡ This is more than 550 miles away.

Of the plants (480 species) no less than 440 are found also in Europe, Madeira, or the Canary Islands; while 40 are peculiar to the Azores, but are more or less closely allied to European species. As the Azores are entirely composed of volcanic rocks, and are surrounded on all sides by a wide expanse of deep ocean, it is improbable that they were ever connected with any continental land. The statistics quoted above warrant the conclusion that the fauna and flora are all colonists, stragglers from the adjacent mainland and islands, which have been wafted by the winds or drifted by the ocean currents, but that sundry of them have been settled there long enough to be so far modified as to be readily distinguishable from their allies on the mainland. The latter also may have possibly diverged slightly from the parent stems. The insulation, in short (if we may so call it), is more complete, and of more ancient date than in the case of the British Isles.

We must refer to Mr. Wallace's most valuable work on "Island Life" for other instances of the same kind, and conclude by briefly noticing the case of Australia and the islands which are usually associated with it in the same zoölogcial province. This, according to Mr. Wallace,* is "the great insular region of the earth. . . Its central and most important masses consist of Australia and New Guinea, in which the main features of the region are fully developed. To the northwest it extends to Celebes, in which a large proportion of the Australian characters have disappeared, while Oriental types are mingled with them to such an extent that it is rather difficult to determine where to locate it. To the southeast it includes New Zealand, which is in some respects so peculiar that it has even been proposed to constitute it a distinct region. On the east it embraces the whole of Oceanica to the Marquesas and Sandwich Islands, whose very scanty and often peculiar fauna must be affiliated to the general Australian type." Zoölogically, the Australian region is different from all the rest of the globe by the entire absence of all the orders of non-aquatic mammalia that abound in the Old World, except the bats (which are winged) and one family of rodents, the *Muridæ* (rats and mice), and the representatives of these are small or moderate in size. The other mammals, except two monotremes†—the lowest in the scale of develop-

* "Geographical Distribution of Animals," ch. xiii.

† The *Ornithorhynchus* and *Echidna*, "probably the descendants of some of those earlier developments of mammalian life which in every other part of the globe have long been extinct."

ment—are all marsupials, which are wonderfully developed in Australia, and exist in the most diversified forms. "Some are carniverous, some herbivorous, some arboreal, others terrestrial. There are insect-eaters, root-gnawers, fruit-eaters, honey-eaters, leaf- or grass-feeders. Some resemble wolves, others marmots, weasels, squirrels, flying squirrels, dormice, or jerboas. . . Yet they all possess common peculiarities of structure and habits, which show that they are members of one stock, and have no real affinity with the Old World forms which they often outwardly resemble. . . The ornithological features of the Australian regions are almost as remarkable as those presented by its mammalian fauna, and from the fuller development attained by the aërial class of birds, much more varied and interesting. None of the other regions of the earth can offer us so many families with special points of interest in structure or habits or general relations. The paradise birds, the honey-suckers, the brush-tongued paroquets, the mound-builders, and the cassowaries—all strictly peculiar to the region—place it in the first rank for the variety, singularity, and interest of its birds."

The reptiles, amphibians, fresh-water fish, insects, and terrestrial mollusca exhibit peculiarities, but are less distinctive, on the whole, than the mammals and the birds; while the plants, notwithstanding the existence of several very marked forms, are sufficiently allied to those of Asia to be combined in one botanical region.* Mr. Wallace,† several years since, called attention to the remarkable proximity in one part of the Oriental and Australasian zoölogical provinces, and the short separation between them. To the east of Java a strait of the sea about fifteen miles wide separates the islands of Bali and Lombok, yet the fauna of the one is distinctly Oriental, of the other no less distinctly Australasian. Mr. Wallace, after a discussion of all the evidence which he could obtain, comes to the conclusion that most probably the Australian region has not been connected with the northern continent since an early date in the Secondary era, and since that time has gone on developing its mammalian fauna into the existing races. Still the variations in the disposition of sea and land within this region have been many. For instance, New Zealand, as he believes, received its flora and fauna from Eastern Australia at a time—probably toward the end of the Secondary era—when the latter was divided by sea from

* See Blanford, Presidential Address to the Geological Society, 1890, p. 82 (Proceedings).
† "The Malay Archipelago," ch. i.

Western Australia, and "the characteristic marsupial and monotreme fauna, with all the peculiar temperate flora of Australia, was confined to the western island."

Many like instances are given by Darwin, Wallace, and other writers on the questions connected with the distribution of life. The evidence collected leads to the following general conclusion: That the fauna and flora of an island are always related to those of some

FIG. 169.—MAP SHOWING HOW THE DEEP NARROW STRAIT BETWEEN BALI AND LOMBOK SEPARATES THE AUSTRALASIAN FROM THE INDO-MALAYAN FAUNA.

neighboring land, and that each member of an island group is connected with the others, and directly or indirectly with the nearest mainland.

If there are links with more than one continent, these will be the strongest in the direction of the place from which migration is most easy. The spread of a land flora and fauna is mainly impeded by seas or (to a less degree) by mountain chains and deserts; that of a marine flora and fauna by land barriers, and to no small degree by great variations in depths. The more marked the divergence between an insular and mainland flora or fauna, the more remote the date of separation. The conclusion seems irresistible that each variety or each species has been differentiated from its nearest ally or allies by the effect of its altered conditions of life; or, in some

cases, that their distinctions are due to a divergence on both sides from a common ancestral type.

So far as regards most insular and some continental floras and faunas, a derivative origin and a modification by alteration of circumstances may be regarded as established by evidence which it would be very difficult to refute. When we come to the great question of the origin of species, which since the publication of Darwin's classic work has influenced and directed the studies of so many naturalists, we may not venture at present to use quite so strong a phrase; but we cannot deny that, although the existence of some difficulties must be frankly admitted, the evidence in its favor has been so much strengthened during the last thirty years that the general accuracy of the leading idea—which occurred independently to Darwin and Wallace—can hardly be doubted. There may be factors at work in causing changes other than those included in the term "Natural Selection." It may be that progress is only possible in certain fairly definite directions: that in consequence of innate tendencies, as they may be called, limits exist, within which only (however wide they may be) variation is possible; in other words, the whole truth in regard to this subject may not yet have been discovered. But we cannot deny, if the matter be viewed without prejudice, that these leaders in science have arrived at a most important truth, and have come much nearer to a complete solution of the mystery than those who maintained any form of the hypothesis of special creation.

Allowance must be made for the imperfection of the geological record, to which attention has already been called,* but, notwithstanding this, it must be admitted that the flora and fauna of any district, whether they be tenants of the land or of the sea, are the descendants of their predecessors in the same region. As they are traced somewhat further back, evidence is frequently obtained of dispersions in different directions and migrations by paths which are sometimes no longer practicable. The type is obviously the outcome of its environment, and the environment, regarded as a whole, may be termed a function of several variables, and is very liable to change. The geography of the earth is modified, as we have seen, by the action of forces from within and from without; by these, and possibly by influences yet more remote in their origin, climate has been altered, and the other circumstances may be made so

* Pp. 332–334.

different as to become either very favorable or very unfavorable to the variation or even to the existence of particular types of living creatures. Apart from such obvious cases as the replacement of sea by land or land by sea, there are many less startling which produce effects often far from unimportant. There are, for example, marked differences in the flora even of any one country, dependent on the soil and the situation of the district. In the British Islands one group of plants characterizes the marshland, another the sandy heaths, a third the chalk hills, and so on; and with these differences in the fauna are more or less closely connected. If a food plant disappears, the animal which is dependent on it is in a "parlous" condition; it must seek "fresh woods and pastures new," or it must perish; and when any living creature begins to travel, or in any way to alter its habits of life, as both the sum total and the constituents of its environment are changed, modification becomes inevitable.

But for a full discussion of this subject we must refer the reader to the classic columns already mentioned, and content ourselves with calling attention to three topics which seem of special interest as bearing on this general question. The first is the direct evidence of modification, due to altered conditions, which is exhibited when the line of descent of some living creature is traced back; the second, the exhaustion which sometimes seems to follow an over-indulgence, as it may be called, in modification; and the third relates to the influence which the human race has exercised in altering the conditions of life on the globe.

As regards the first: changes in the conditions of life lead to the development of organs which are constantly in requisition and to the abortion of those which fall into disuse. It will suffice to notice the latter case, because the existence of an aborted organ bears more directly upon the rival hypotheses of special creation and of evolution. As an example it is difficult to find a better instance than that so often quoted—the genealogy of the horse. The foot of the living group—of which *Equus caballus* is the type—consists of one large digit (No. III., E), on either side of which is a thin long bone (the splint bone). This animal first appears at the top of the Pliocene deposits (in India), and among the earliest forms some modifications are taking place, especially in the molar teeth, which bring the genus very near to a Pliocene genus, called *Hipparion*, found in both the New World and the Old, where the splint bones are replaced (D) by two small but fairly complete digits (No. II., IV.).

In C we have the form of the foot in *Anchitherium*, an animal belonging to the Miocene period, where the side digits are larger (II., IV.) compared with the middle one (III.); and then we are led by some transitional Upper Eocene forms resembling *Palæotherium* (B) to *Hyracotherium* of the Lower Eocene, where the forefoot, which is like that of a tapir (A) has four complete digits (as marked),

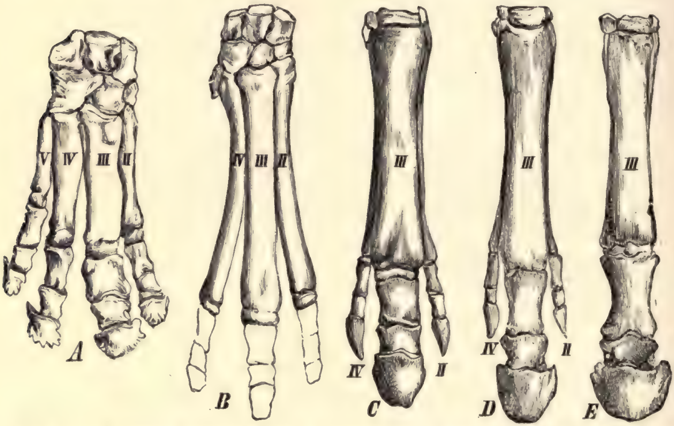


FIG. 170.—VARIOUS FORMS OF FEET, ILLUSTRATING DEVELOPMENT OF ONE DIGIT AND ABORTION OF OTHERS.

A, Tapir; B, Palæotherium; C, Anchitherium; D, Hipparion; E, Horse.

and an allied creature (*Eohippus*) has even rudimental indications of the fifth digit. Finally the earliest stage of the series is formed by an animal (*Phenacodus*) of the Lowest Eocene of North Amercia, in which there are five digits to each foot. Mr. Lydekker, on whose authority these statements are given, calls attention to a remarkable circumstance in the line of evolution culminating in the modern horse. "A parallel series of generically identical or closely allied forms occur in the Tertiaries of both Europe and North America, from which it has been suggested that in both continents a parallel development of the same genera has simultaneously taken place—*i. e.*, that in both regions *Anchitherium* has given rise to *Hipparion*, and *Hipparion* or an allied type to *Equus*. Now seeing it is evident that in the case of species of a single genus the evolution has taken place in separate lines—that is to say, the existing Indian species of *Canis* are probably derived directly from the Pliocene

forms of the same region, and the Brazilian species of that genus have their predecessors in the cave epoch of that country—there appears no logical reason for refusing to admit an analogous parallel evolution in the case of genera, and there is accordingly a considerable probability that the hypothesis may be a true one."*

The genealogy of other forms, both vertebrate and invertebrate, has been traced, one or two cases of which have been incidentally noticed elsewhere in this book. The evidence, on the whole, is so strong that even those palæontologists who are still indisposed wholly to abandon the old idea of a special creation of certain original types are compelled to admit that very great variation has occurred, and that not a few groups of living creatures must have diverged from some primary and ancestral form. They would also admit that these exhibit on the whole a progress from the general to the specialized, from the more embryonic to the more highly developed in structure, while the disused organs become abortive.

In the second place, there is some evidence to show that after an assemblage of living creatures has attained in the process of evolution to a certain stage of specialization, such as would be expressed in classification by placing the members in the same genus or close association of genera, their original stock of vital energy, if the phrase be permissible, seems to be so far limited as to be liable to exhaustion. As a general rule a genus, family, or even order, when it first appears, is not for a time very abundant, as though it had to fight for its existence against somewhat adverse conditions. Sometimes, indeed, it fails to make good its footing. It continues for a while, but is never numerous, either specifically or even individually. Finally it disappears, and may be counted among Nature's failures.† Other groups, however, win their way, species and even genera becoming numerous, and the individuals in them abundant. These, after a period of prosperity, sometimes fairly prolonged, seem to feel the advance of senile debility; they dwindle, and at last either totally disappear from the earth or are represented by descendants few and insignificant. Of such a "decline and fall," which has its parallels in the history of man, instances are numerous. The trilobites had already begun their existence when the earliest fossiliferous rocks were deposited. They increase through the Cambrian and Ordovician systems, reaching a maixmum in the Bala group,

* Nicholson and Lydekker, "Manual of Palæontology," p. 1363.

† Such, for example, were the Cystoidea and Blastoidea in the Primary era.

and then gradually decrease, until, in the course of the Carboniferous period, they totally disappear. The genus *Trigonia* among the ordinary bivalve mollusca, and *Terebratula** with its nearest relations, were very abundant during the Secondary era. Since then they have waned, and now have but a few representatives. The Belemnites also prospered through the greater part of the same era, and then rather quickly disappeared. Yet more remarkable is the case of the family of the Ammonitidæ, which also appeared in Europe at the beginning of this era, and established themselves in Britain almost step by step with the advancing sea. They were represented for a long time by a considerable number of species, and frequently were individually very abundant. Then, toward the close of the era, their power of variation seems to be much more conspicuously exhibited. It appears as though in a struggle either for predominance or against conditions which it was felt were becoming unfavorable, they attempted to grow after many and often very diverse types†—then their vitality, almost suddenly, becomes exhausted, and the whole family vanishes from the earth.

Lastly, the results which have been produced by man himself furnish us with an object lesson illustrative of the changes which may have occurred in past ages during the "struggle for existence." In his case too there must have been danger for a time, lest the "beasts of the field" should prevail over him; but as he drew wider apart from them by progress in civilization, more destructive instruments were substituted for the first rude weapons of the savage, and he became the destroyer of species after species. Without entering upon the more debatable question of the causes which have been destructive to the great mammals which were contemporaneous with palæolithic man—such as the mammoth, the woolly rhinoceros, the Irish elk, and the like—we may point to the changes which have occurred in historic times. Many of these have been already mentioned, but even this century has seen some changes. The drainage of the Fens destroyed the Great Copper butterfly (*Lycæna dispar*), and from some unknown cause the Mazarine Blue (*Polyommatus acis*) has also perished. During the same period the wildcat, the marten, the polecat, the badger, with may other animals and some plants, have become rarities in Britain; and in many parts of Africa, Asia, and North America both big game and the larger carnivora have become more and more scarce.

* This genus first appears at a considerably earlier date.

† Pp. 435, 436.

The lists of extinct and disappearing animals might have been readily increased, but the instances quoted may suffice to show what changes have been wrought in the fauna of the globe by man's appetite for flesh or by his passion for the chase. The effects of these are far reaching. The destruction of carnivorous animals removes enemies to animals commonly herbivorous. The destruction of the latter alters the balance of forces in the vegetable world. At St. Helena, we are told, the forests on the hills have been almost destroyed by the goats turned loose from vessels; the sparrow in more than one part of the world, the rabbit in Australia, show that man's efforts to modify the course of Nature for his own advantage are not always attended with success. If keepers had refrained from harrying the Little Owls, the farmers in Scotland most probably would not have been, as of late, plagued by voles.

But the results of man's interference appear yet more conspicuous when he has operated directly on the vegetable world. The necessity of clearing the land for cultivation, or the greed of gold, causes the wholesale destruction of forests. By this not only is the rainfall affected, but also, when the shower falls, the water, instead of sinking quietly into the ground, collects into runlets and quickly tears away the soil, now unprotected by the leaves and no longer bound together by the roots of trees. Torrents of mud and gravel go raging down the ravines, choking the channels of the lowland rivers and flooding the plains with the *débris* of the mountains. Réclus, in the book from which we have more than once quoted, draws a vivid picture of the ravages which have been initiated by man.* "When the forests are gone, great furrows of erosion may be noticed opening out at intervals on the slopes; these furrows often correspond to ravines situated on the other side of the mountain, and in a comparatively short space of time they ultimately sever the ridge of the mountain into distinct peaks, uniformly surrounded by a slope of rocks or fallen earth. Summits of this kind are being formed every year. In some localities there is not a single green bush over a space of several leagues in extent; the scanty, gray-colored pasturage is scarcely visible here and there on the slopes, and ruined houses blend with the crumbling rocks that surround them. The stream in the valley is generally nothing but a scanty rill of water winding among the heaps of stones; but these very heaps of shingle and rock have been carried down by the tor-

* "The Earth," part iii. ch. xlvii.

rent itself in the days of its fury. In many parts of its course the Haute Durance, which is generally not more than thirty feet wide, seems lost in the midst of an immense bed of stones a mile and a quarter wide from bank to bank. The Mississippi itself does not equal it in dimensions.

"The devastating action of the streams in the French Alps is a very curious phenomenon in an historical point of view, for it explains why so many of the districts of Syria, Greece, Asia Minor, Africa, and Spain have been forsaken by their inhabitants. The men have disappeared along with the trees; the ax of the woodman, no less than the sword of the conqueror, have put an end to or transplanted entire populations. At the present time the valleys of the Southern Alps are becoming more and more deserted, and the precise date might be approximately estimated at which the departments of the Upper and Lower Alps will no longer have any home-born inhabitants. During the three centuries that have elapsed between 1471 and 1776 the *vigneries* of these mountainous regions have lost a third, a half, or even as much as three-quarters of their cultivated ground, and the men have disappeared from the impoverished soil in the same proportion. From 1836 to 1866 the Upper and Lower Alps have lost 25,090 inhabitants, or nearly a tenth of their population. . . It is the mountaineers themselves who have made and are seeking to extend this desert which separates the valleys of the Rhone from the populous plains of Piedmont. If some modern Attila, traversing the Alps, made it his business to desolate these valleys forever, the first thing he should do would be to encourage the inhabitants in their senseless work of destruction. Is it necessary that man must ultimately rid the mountains of his odious presence, so that the latter, left to the kind offices of beneficent Nature, may again some day recover their forests of fir trees and their thick carpet of flower-studded turf?"

The statements are strong, the words severe, yet they are hardly too strong or too severe. In parts of Europe and Asia the mischief which has been wrought by the reckless destruction of the forests, especially in the mountain regions, is almost beyond calculation; parts also there are of North America which will have to pay the penalty for a like ill doing. Doubtless in many cases a set-off can be pleaded; the land must be cleared if it is to be cultivated, and the cornfield may feed more mouths than the forest; but often the work of destruction has been so selfish and reckless, actuated by the lust of a temporary gain, without the slightest thought of the

effect either on others in the present or on the race in the future, as to be almost inexcusable. Not seldom, as in some of the American forest fires, the mischief is the outcome of that savage love of destruction which it would be a misnomer to call brutal and bestial, because it is the attribute of man so much more conspicuously than of the animal world.

The same author points out, in another place,* that climatal changes also result from the cutting down of trees. By that the rainfall undoubtedly is diminished, and this may be a serious evil in districts where it is already light. To such a cause the present aridity of the Sinaitic peninsula and of the southern parts of Palestine is probaly due. In the days of the Exodus the dry plateau of the Tih "must have borne a similar relation to the then fertile region of the Negeb which that now barren tract at the present day bears to Palestine."† In those days the vine was cultivated freely on the rocky slopes of the South Country, and the Land of Promise was "a land of brooks of water, of fountains and depths that spring out of valleys and hills." Réclus states‡ that the clearing away of forests "effects a change in the network of isothermal, isotheral, and isochimenal lines which pass over the country. In several districts of Sweden where the forests have been recently cut down, the springs at the present time commence, according to Asbjiörnsen, about fifteen days later than those of the last century. In the United States the vast clearings which have been made on the slopes of the Alleghanies appear to have rendered the temperature more variable, and have caused autumn to encroach upon winter, and winter upon spring. Generally speaking, it may be stated that forests—which in this respect may be compared to the sea—diminish the natural differences of temperature between the various seasons; while their destruction exposes a country to all the extremes, both of cold and of heat, and adds still greater violence to the atmospheric currents."

Evils more localized, but not seldom highly pernicious, arise from industrial processes, such as mining and manufacturing, and even from the growth of cities. There, around some chemical works, almost for miles, vegetation is destroyed; there the land is smothered beneath piles of rubbish, whence issue foul vapors or fetid smoke; there the streams are polluted with the waste

* "The Ocean," part iii. ch. xxvii.

† Prof. E. H. Palmer, "The Desert of the Exodus," part ii. ch. iv.

‡ "The Ocean," part iii. ch. xxvii.

products of factories or the filth of sewage, and the air is dense with particles of carbon and sulphurous vapors. What can be more unutterably desolate and dreary than such a region as the "Black Country" of South Staffordshire, or the environs of a great manufacturing town, such as one of those in Lancashire? Even the advance of a so-called "residential quarter" is a cheerless sight; for the rigidity of dusty roads, however well made, and the monotony of streets of modern villas, even if not "jerry-built," are a poor exchange for the green sward and the shady foliage of trees.

Extenuating circumstances may, no doubt, be pleaded; for these plague spots on the face of Nature are often the sources of national prosperity. But a little care, a little forethought, a little self-restraint, would have averted many of the greater evils. Man has an unlucky habit—often through thoughtless ignorance or sheer blundering—of "making the worst of both worlds," as it may be called, and doing much mischief in general, with little good to himself in particular. Credit, however, may be claimed, not seldom, for good deeds. If the earth in some places is rendered pestilential by man, in others it is made more healthy—malarious marshes have been drained, and thus fevers, once endemic, have been mitigated or have disappeared. Houses are beginning to be built on the low plain of the Tuscan Maremma, and the peasants no longer find it always necessary to retreat each night from their work to the neighboring hills. Even in our own land the drainage of the East Anglian fens has made ague an almost unknown disease, and has replaced miles of waste marsh by fertile fields, where the corn in summer "is like a golden ocean becalmed upon the plain." By the planting of trees in arid lands the rainfall has been increased, and by the same means such countries as those which have been already named may be once more rendered productive. It seems inevitable that in the progress of our race we must do some harm. Railways, steamships, mines, factories, even towns, as a rule, are more or less of eyesores in the landscape. All that is beautiful—whether of flowers or insects or birds—seems to vanish from before the face of man, in much the same way as the feebler races of his own species disappear before the stronger. Still man makes waste places fertile, and brings distant lands into closer union; he makes a higher civilization possible, and gives the opportunity for wider knowledge and deeper thought. But much more good and much less harm might be done. When wiser counsels prevail, when the lessons learned from Nature are listened to by statesmen and so-

called practical men—then a better day may dawn, and the advance of civilization be less often a synonym for the triumph of the commonplace, or even of the degrading. Then, perhaps, a reverence for the beauty of Nature may be carried so far that the worshipers of Mammon may be forbidden to mar* its fairest scenes with hideous advertisements of the fabrications by which their money bags are filled, or nearly to poison a neighborhood with the smoke and vapors of their factories.

The outlook for the human race is not at present hopeful. The reign of millennial peace, so confidently prophesied forty years ago, seems farther off than ever, and the destruction of European civilization seems rapidly becoming possible—not, as in the case of the Roman Empire, by the incursion of barbarian races from without, but by the eruption of the savages within its own circle. There was some hope for the future when civilization was trampled down by a horde of lusty children; but what is there when it is destroyed by its own waste products? The teaching of Nature, however, is hopeful on the whole, though it is not always so for the individual, or even for the race. The long annals of the past bear testimony to a growth and a development which are so conspicuous that we would fain hope that our own race has not yet reached the limit of its possibilities or the measure of its appointed time; for the history of the earth is one continuous illustration of the truth of the poet's words:

> "The old order changeth, yielding place to new,
> And God fulfills Himself in many ways,
> Lest one good custom should corrupt the world."

* An oblong, about 40 yards square, on a smooth cliff by the Devil's Bridge (Switzerland) is painted red and inscribed with advertisements (1893). Above it is a pictur of the devil. Very appropriate !

THE END.

GLOSSARY*

of a few geological terms in this book, which either have been used without explanation or may be readily forgotten—Zoölogical and Botanical terms not included.

Agglomerate.—A name often given to the fragmental materials ejected by a volcano when they are mostly of large size: say, from as big as cricket balls upward.

Augite.—A mineral which is a *silicate* of magnesia, lime, and iron; usually green or dark in color.

Basalt.—A rock of igneous origin, dark in color and compact in structure, composed chiefly of a *felspar*, *augite*, some iron oxide, and often *olivine.*

Chert.—Differing only from flint in being rather less pure, and so consisting mainly of *silica*, much, if not all of it, in a crystalline condition.

Chlorite.—A group of minerals resembling *mica* in general habit; green in color. The chief constituents are silica, magnesia, iron, alumina, water.

Cipollino.—A variety of *marble* in which a greenish mineral is present, arranged in layers more or less wavy. Thus a section of the rock has an arrangement like the coats in the bulb of an onion (It. *cipolla*), whence the name.

Dolerite.—Closely allied to *basalt*, of which it may be called a coarse-grained variety. It is also very near to *gabbro.*

Dolomite.—See p. 152.

Felspar.—A group of minerals differing somewhat in form and composition. All are *silicates* of alumina; some also contain potash (this is common in *granite*), others soda, others lime or lime and soda (this is common in *basalt*).

Felstone.—A rock of igneous origin, compact in structure, often chemically identical with *granite.*

Gabbro.—Composed of the same minerals as *basalt*, and differing only in that it is coarsely crystalline and contains usually a special variety of *augite*, which has a "platy" structure.

Garnet.—A very varied group of minerals, the commonest being wine-

*A word printed in italics in an explanation will be found elsewhere in the Glossary.

red; they are all *silicates* of alumina, and among other possible constituents are iron, magnesia, lime, and manganese.

Glauconite.—A mineral chiefly consisting of silica, alumina, iron, potash, and water.

Gneiss.—A rock composed of the same minerals as granite, but exhibiting a certain parallel ordering called foliation. (See p. 291.)

Granite.—A rock of igneous origin, composed of crystalline constituents, the principal being *quartz*, *felspar*, *mica*.

Graphite.—Mineral carbon. (The familiar "blacklead" is graphite.)

Gypsum.—Sulphate of lime combined with water, and in a crystalline condition, occurring in masses.

Hornblende.—A mineral which is a silicate of magnesia, lime, and iron; usually green or dark in color; chemically identical with, but mineralogically distinct from, *augite*.

Hydrous.—In chemical combination with water.

Marble.—A rock formed, properly speaking, wholly, or almost wholly, of crystalline carbonate of lime, differing from ordinary limestone in that all its constituents are in a crystalline condition; but, popularly, the word is often extended to include any limestone which will take a polish.

Mica.—A group of minerals of "platy" habit, with a metallic luster; some light, some dark in color. The chief constituents are silica, alumina, potash or soda (sometimes lithia), and in one group iron and magnesia. The "talc" of commerce is a mica.

Obsidian.—A glassy rock of igneous origin, often chemically identical with *granite*.

Olivine.—A mineral which is a silicate of magnesia and iron, generally yellowish or somewhat green in color.

Peridotite.—See p. 260.

Pitchstone.—Nearly the same as *obsidian*.

Pumice.—A volcanic rock full of cavities formed by steam, commonly more nearly related to *trachyte* than to *basalt*.

Pyroxene.—A name generally used as the equivalent of *augite*, but which of late years has been employed in a wider sense, so as to include *hornblende* and one or two closely allied minerals.

Quartz.—The usual form in which *silica* (oxide of silicon) crystallizes.

Quartzite.—A hard rock composed of grains of *quartz* agglutinated together so that they are sometimes indistinct. Probably in all cases it was once a sandstone.

Rock salt.—Chloride of sodium in a crystalline condition, occurring in masses, from which salt (used for cooking, etc.) is obtained.

Schist.—A crystalline foliated rock. (See p. 291.) When the name of a mineral is prefixed, this indicates that the mineral is abundant in the schist.

Serpentine.—See pp. 260 and 291.

Silica.—Oxide of silicon ; quartz is the commonest crystallized form ; opal and siliceous sinter are colloid varieties.

Silicate.—*Silica* in chemical combination with other substances.

Sill.—A local term applied to sheets of igneous rock, when they have been thrust uniformly between strata, like a card between the leaves of a book.

Staurolite.—A silicate of alumina and iron, dark brown in color.

Till.—A glacial deposit. The word is employed by some as equivalent to bowlder clay, by others it is restricted to such deposits when the materials have come from quite near at hand.

Trachyte.—A volcanic rock, differing from *felstone* in being yet more compact, and even glassy.

Travertine.—A rock composed of carbonate of lime precipitated from water, practically identical with tufa.

Tripoli.—See p. 176.

Tuff.—A term used in this work to indicate the less coarse and more distinctly bedded kinds of volcanic ash : *tufa* denoting a precipitate of carbonate of lime from water.

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